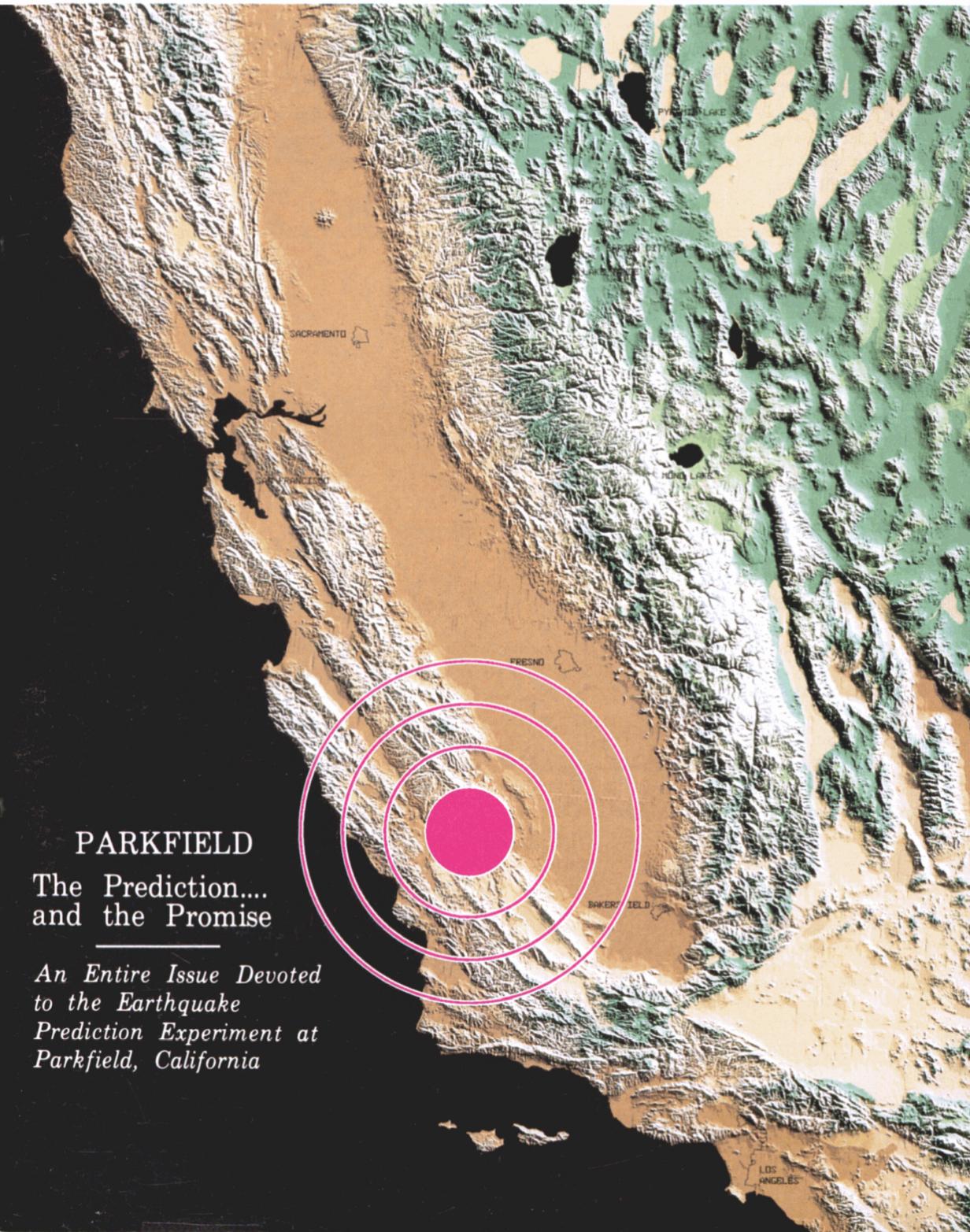




Earthquakes & Volcanoes

Volume 20, Number 2, 1988



PARKFIELD
The Prediction....
and the Promise

*An Entire Issue Devoted
to the Earthquake
Prediction Experiment at
Parkfield, California*

UNITED STATES DEPARTMENT OF THE INTERIOR
Donald Paul Hodel, Secretary

U.S. GEOLOGICAL SURVEY
Dallas L. Peck, Director

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Cover: From an unpublished USGS shaded-relief map of the southwestern United States compiled by Kathleen Edwards, R.M. Batson, and E.M. Sanchez. The relief is a computer portrayal, using this particular color scheme for visual effect only.



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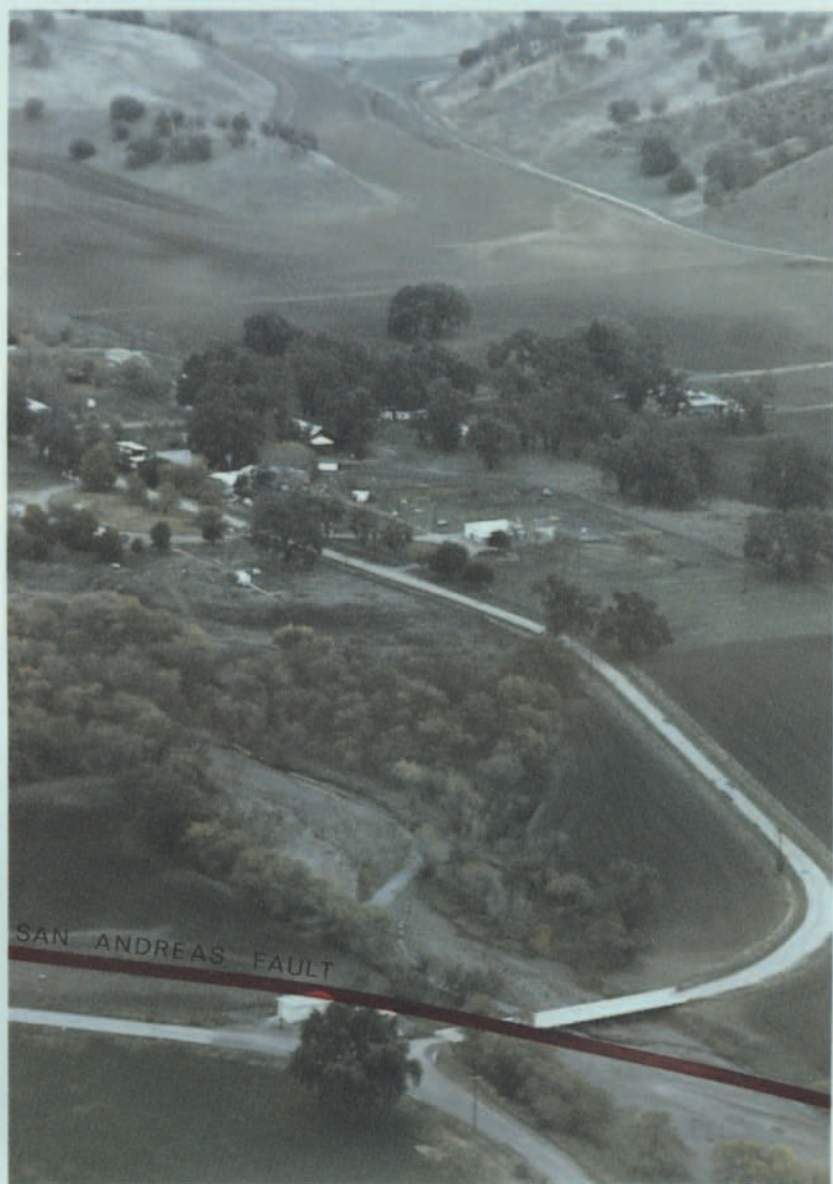
Richard Andrews and James Goltz

Suggested Reading

Editor's Note

This issue of *Earthquakes and Volcanoes* is devoted entirely to the subject of the Parkfield earthquake experiment in central California. In this area of California, near the small town of Parkfield, the San Andreas fault is expected to rupture before 1993 from an earthquake of approximately magnitude 6—a significant shock. The articles in this report are arranged to cover the Parkfield story, both an earthquake prediction and a major scientific study, in a particular way—first introducing the idea of regularly occurring significant earthquakes in the Parkfield area, the Federal role in such earthquake predictions, the specific instrumentation at Parkfield, the scientific goals of the experiment, the USGS prediction plan, and the State response to the prediction. Because each article builds on the preceding articles, this issue is best read from the beginning.

Town of Parkfield, Calif., lies a few hundred meters east of main trace of San Andreas fault. Parkfield bridge (foreground), built in 1932, was damaged in 1934 and 1966 Parkfield earthquakes.



INTRODUCTION

William H. Bakun
U.S. Geological Survey
Menlo Park, California

In April 1985 the U.S. Geological Survey (USGS) issued a prediction that an earthquake of approximately magnitude 6 would occur before 1993 on the San Andreas fault near Parkfield, California (population 34), located in a sparsely populated area of central California midway between San Francisco and Los Angeles. The Parkfield prediction is the first officially recognized scientific prediction of an earthquake in the United States.

On September 30, 1985, California Governor George



Index map of California showing location of Parkfield and generalized trace of San Andreas fault.

Earthquake magnitude, first defined in 1935 by Charles F. Richter, is a measure of the size of an earthquake. For each unit of magnitude the amplitude of ground motion (or seismic waves) increases by a factor of 10. Thus a magnitude 6 earthquake, such as the predicted Parkfield main shock, produces ground motions that are 10 times greater than those from a magnitude 5 earthquake. The energy released as seismic waves by an earthquake increases even faster, a factor of 33 increase for each unit of magnitude. As shown below there are limits to the sizes of detected earthquakes, but there are no well established limits to the possible sizes of earthquakes.

<i>Magnitude</i>	<i>Energy released (millions of ergs)</i>	<i>Energy equivalence</i>
-2	600	100 watt light bulb left on for a week
-1	20000	Smallest earthquakes detected at Parkfield
0	600000	Seismic waves from one pound of explosives
1	20000000	A two-ton truck traveling 75 miles per hour
2	600000000	
3	20000000000	Smallest earthquakes commonly felt
4	600000000000	Seismic waves from 1,000 tons of explosives
5	20000000000000	
6	600000000000000	Parkfield earthquakes: 1934, 1966, 19?
7	2000000000000000	
8	60000000000000000	1906 San Francisco (magnitude=8.3)
9	200000000000000000	Largest recorded earthquake (magnitude=8.9)
10	6000000000000000000	

Deukmejian signed Assembly Bill 938, authored by former Assemblyman Richard Alatorre, which appropriated \$1 million of State funds to be matched by \$1 million of federal funds to develop a "prototype earthquake prediction experiment" at Parkfield. These funds provided for a significant increase in the geophysical instrumentation near Parkfield, making the Parkfield section of the San Andreas fault without question the most densely and comprehensively instrumented earthquake source region in the world.

The primary goal of the Parkfield prediction experiment is a detailed understanding of the geologic processes that precede the anticipated earthquake. Scientists want to know what happens in the weeks, days, hours, and minutes before the earthquake in order to more confidently address such questions as: Are short-term warnings (weeks to days—or minutes—before an earthquake) generally feasible? What earthquake-prediction techniques can be used in areas of significant seismic hazard, such as metropolitan Los Angeles and San Francisco?

A secondary goal of the Parkfield experiment is for the USGS to issue a short-term warning of the anticipated earthquake. Although such a warning cannot now be reliably made, a plan of alert levels has been devised as part of the process for evaluating the capability of providing short-term warnings.

Clearly, if the Parkfield experiment shows that specific, measurable changes occurred just before the anticipated earthquake, whether or not a short-term warning is issued, the reality of short-term warnings of earthquakes may be closer at hand. But a major caveat exists: Parkfield, like every earthquake source

region in our complicated world, has unique geologic features, and so what occurs before any Parkfield earthquake need not necessarily occur before shocks elsewhere. Even if short-term warnings at Parkfield become feasible, earthquakes in other areas may remain unpredictable. Whatever is learned about earthquake prediction at Parkfield will need to be tested in Parkfield-like experiments in other seismically active regions.

One additional major question is what happens if some, or perhaps all, the monitoring instruments used in the experiment record no changes before the anticipated shock. One conclusion of the Parkfield experiment would then necessarily be that short-term warnings for magnitude 6 shocks are difficult, perhaps not possible at all. In this regard, it is worthwhile to note that experience in the People's Republic of China suggests that whereas magnitude 6 shocks are exceedingly difficult to predict, precursors to magnitude 7 and larger shocks are comparatively easy to recognize and occur over a broad area.

It is clear that the prototype Parkfield earthquake prediction experiment is an important step in efforts to reduce seismic hazard by developing earthquake-prediction techniques. However, Parkfield is only one step in a long scientific process. While the results of the Parkfield experiment likely will guide future developments in the goal to reduce seismic hazards, Parkfield by itself will neither prove nor disprove the feasibility of reliable earthquake predictions or short term warnings.



"The Far Side" cartoon by Gary Larson is reprinted by permission of Chronicle Features, San Francisco, California

The mysterious, innate intuition of some animals

PARKFIELD PREDICTION: QUESTIONS AND ANSWERS

Modified from "The Parkfield Earthquake Prediction," published by the Southern California Earthquake Preparedness Project [available from the Governor's Office of Emergency Services, 2800 Meadowview Rd., Sacramento, CA 95832].

1. What is the Parkfield earthquake prediction experiment?

On the basis of state-of-the-art research, scientists have predicted that a moderate-sized earthquake, about magnitude 6, is likely to occur near Parkfield, California, before 1993.

Scientists from the United States Geological Survey (USGS) and the California Division of Mines and Geology (CDMG), along with colleagues from around the world, have installed sensitive instruments near Parkfield. These instruments are designed to detect changes in the earth that may occur a few hours or a few days before the next Parkfield earthquake.

The USGS is conducting an experiment to make a short-term prediction of the next Parkfield earthquake. *A short-term prediction means that the likelihood of an earthquake occurring within a specified period has increased, not that an earthquake is certain to occur.*

2. Why try to predict earthquakes?

Central California, like the entire state, is earthquake country. Damaging earthquakes happen frequently, and very large earthquakes are forecast for areas of the State. If scientists could predict some earthquakes, we might save lives and reduce property losses.

Because earthquakes are a threat worldwide, many countries might benefit from reliable predictions. Both Japan and China have prediction efforts. Parkfield is considered to be the premier prediction experiment in the world.

3. Why Parkfield?

Earthquakes similar to that predicted have happened near Parkfield with regularity—in 1966, 1934, 1922, 1901, 1881, and 1857. There is evidence that small earthquakes and movement along the fault occurred in the days just before the last Parkfield earthquake.

4. Will the magnitude 6 earthquake cause any damage?

In 1966, 1934, and 1922 damage was minor. Around Parkfield some windows, chimneys, plastered walls and glassware were affected. Surrounding communities such as Paso Robles, Coalinga, San Miguel, and Avenal had slight impact like merchandise falling from shelves and a few broken dishes.

5. Could the next Parkfield earthquake be larger?

Possibly, though scientists have advised the State that it is unlikely. Some scientists have said the earthquake could be as much as magnitude 7. The California Earthquake Prediction Evaluation Council (CEPEC) has advised the Office of Emergency Services (OES) that it would be prudent to plan on the assumption that the bigger earthquake might happen.

6. How will people learn about a short-term Parkfield prediction?

Radio, television, and newspapers in the counties around Parkfield will announce the prediction after being notified by local and State officials. They will continue to provide advice to citizens.

7. What happens if the earthquake doesn't occur?

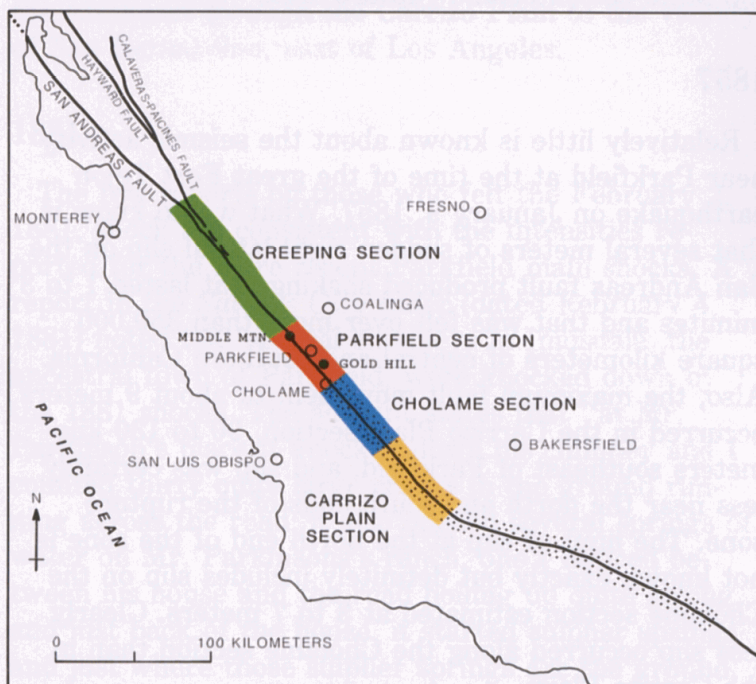
If the earthquake doesn't occur within 72 hours (3 days) after the warning is announced, it is likely that the USGS will advise the State to cancel the warning, unless the instruments at Parkfield continue to suggest that there is a significant chance that the earthquake will occur. Radio, television, and newspapers will carry the announcement that either cancels or extends the alert period.

It is very possible that one or two warnings may be issued without the earthquake occurring. An earthquake prediction means that the chances of an earthquake occurring are greater for the 3-day period, not that the earthquake is certain to occur.

History of Significant Earthquakes in the Parkfield Area

William H. Bakun
*U.S. Geological Survey
Menlo Park, California*

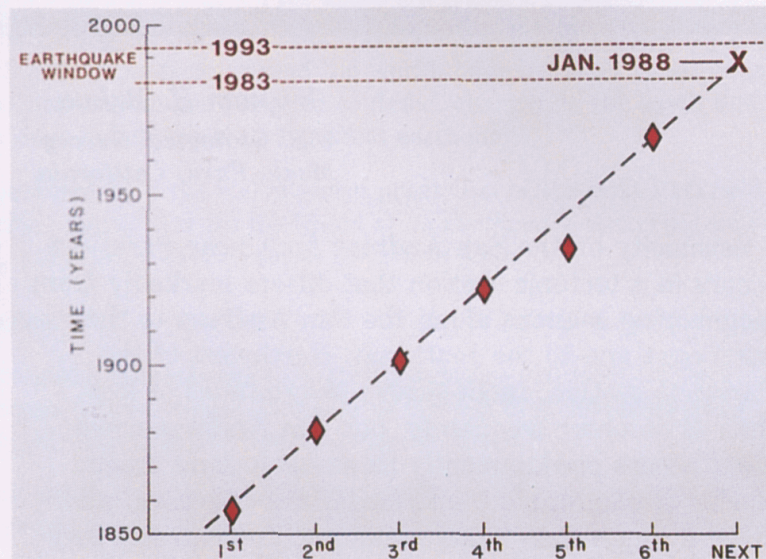
Seismicity on the San Andreas fault near Parkfield occurs in a tectonic section that differs markedly from neighboring sections along the San Andreas to the northwest and to the southeast. Northwest of the Parkfield section, small shocks (magnitudes of less than 4) do occur frequently, but San Andreas movement occurs predominantly as aseismic fault creep; shocks of magnitude 6 and larger are unknown, and little, if any, strain is accumulating. In contrast, very few small earthquakes and no aseismic slip have been observed on the adjacent section to the southeast, the Cholame section, which is considered to be locked, inasmuch as it apparently ruptures exclusively in large earthquakes (magnitudes greater than 7), most recently during the great Fort Tejon earthquake of 1857. The Parkfield section is thus a transition zone between two sections having different modes of fault failure. In fact, the regularity of significant earthquakes at Parkfield since 1857 may be due to the nearly constant slip rate pattern on the adjoining fault sections. Until the magnitude 6.7 Coalinga earthquake



Tectonic sections of San Andreas fault in central California. Colors delineate sections, which are discussed in text. Patterned area represents surface rupture during 1857 Fort Tejon earthquake.

Significant earthquakes have occurred on the Parkfield section of the San Andreas fault at fairly regular intervals—in 1857, 1881, 1901, 1922, 1934, and 1966. The next significant earthquake is anticipated to take place within the timeframe 1983 to 1993.

on May 2, 1983, 40 kilometers northeast of Parkfield, the Parkfield section had been relatively free of stress changes due to nearby shocks; the effect of the Coalinga shock on the timing of the next Parkfield shock is not known.



Although numerous small shocks occur continually on the Parkfield section, the seismicity since 1857 has been dominated by magnitude 6 earthquakes (with associated foreshocks and aftershocks) in the years 1881, 1901, 1922, 1934, and 1966. Although the quantity and quality of the information decrease dramatically for the earlier shocks, all available data point to these significant earthquakes at Parkfield as being “characteristic”; that is, shocks of approximately magnitude 6 occurring every 21 to 22 years and having the same epicenter and rupture area.

1857

Relatively little is known about the seismic activity near Parkfield at the time of the great Fort Tejon earthquake on January 9, 1857. What we do know is that several meters of sudden right-lateral slip on the San Andreas fault produced shaking that lasted 1 to 3 minutes and that was felt over more than 350,000 square kilometers of central and southern California. Also, the maximum fault movement of about 9 meters occurred in the Carrizo Plain section, 90 to 130 kilometers southeast of Parkfield, and slip was certainly less near the north and south ends of the rupture zone. The limit of slip at the north end of the zone is not known exactly but definitely includes slip on the Cholame section estimated at 3 to 7 meters. Clearly less slip occurred along the Cholame section than in the Carrizo Plain.

Although more than 130 years have passed since the great Fort Tejon earthquake, there is little reason to anticipate a repeat of that event in the next several decades. Crustal deformation measurements along the San Andreas fault southeast of Parkfield indicate that plate movement is straining the region at a rate corresponding to 3 centimeters per year of right-lateral slip. Thus the movement since 1857 has not been sufficient to repeat the 9 meters of slip that occurred on the Carrizo Plain section in 1857. However, it is uncertain whether the potential for the 3 to 7 meters of slip that apparently occurred along the Cholame section in 1857 has been recovered by crustal straining along the fault since then. Thus it is possible, though not likely, that the anticipated magnitude 6 Parkfield earthquake might trigger, or "grow into," a shock of about magnitude 7 on the Parkfield and Cholame sections.

Accounts of the 1857 earthquake indicate that several small to moderate size central California shocks preceded it by 1 to 9 hours. In particular, two foreshocks were widely felt. A study of the felt areas and intensities of these two foreshocks by Professor Kerry Sieh of the California Institute of Technology indicates that they were similar to the Parkfield main shocks of 1901, 1922, 1934, and 1966. Sieh concluded that the 1857 foreshocks were magnitude 5 to 6 earthquakes located within an area that includes the Parkfield section. Because foreshocks generally occur near the epicenter of the ensuing larger main shock, Sieh believed the slip in the great Fort Tejon earthquake actually began near Parkfield at the northwest end of the 1857 rupture zone and extended along the fault to the southeast through the Carrizo Plain to the vicinity of San Bernardino, east of Los Angeles.

1881

The few reports by those who felt the February 2, 1881, shock are consistent with the intensities reported for the more recent Parkfield main shocks. A report in the *Salinas City Index* (dated February 4, 1881) noted that several chimneys in Imusdale, the ancestral town of Parkfield, were knocked down by the 1881 shocks. The account states that "at Mr. Parkinson's place it knocked down his chimney and I counted thirty quite large cracks in the ground running across the road; it also opened several springs of water on Mr. Parkinsons's ranch, one I noticed between his house and the road boiling up quite strong, and just back of the house, it started sulphur springs and just where those sulphur springs are the ground, about 20 paces square, is sunk about 4 feet." Charles

Real of the California Division of Mines and Geology used the records of the Monterey County Assessor's Office to locate Mr. Parkinson's property ($N\frac{1}{2}NE\frac{1}{4}$ and $N\frac{1}{2}NW\frac{1}{4}$, sec. 28, T. 23 S. R. 14 E.) a few kilometers northwest of Parkfield, a location that spanned a zone of cracks observed after the 1966 Parkfield earthquake.

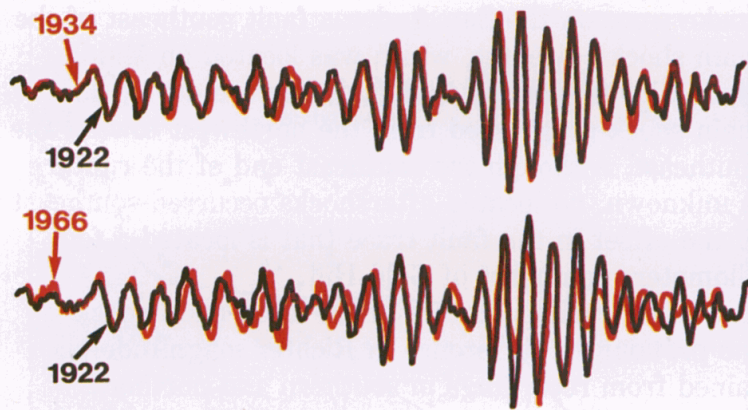
1901

A seismic intensity map by Kerry Sieh for the March 3, 1901, earthquake suggests that the area of strong shaking was about twice that of the 1966 earthquake, suggesting a somewhat larger magnitude for 1901. Moreover, a comparison of the shaking intensities for the 1922, 1934, and 1966 shocks indicates larger magnitudes for the 1922 and 1934 shocks, even though seismograms require nearly identical seismic movements for these three shocks. One conclusion is that intensity data do not reflect small differences in magnitude. Nevertheless, the intensities of the 1901 shock suggest that it was somewhat larger than the later Parkfield shocks, although whether the difference is significant it is not clear.

An account of the ground cracking near the San Andreas fault in 1901 is contained in a letter (dated May 17, 1905) to H.F. Reid of John Hopkins University by Homer Hamlin, an engineer employed by the U.S. Geological Survey in Yuma, Arizona. Interpretation of Hamlin's account is difficult because the locations of his observations are not precise, and he does not adequately differentiate cracks due to landslide and slumping from cracks directly related to offsets at the fault. Hamlin describes extensive cracking northwest of Middle Mountain, the northwest end of mapped tectonic surface cracks from the 1966 earthquake. However, the area along the San Andreas fault northwest of Middle Mountain is characterized by extensive landslide features, and so landsliding and slumping there during the 1901 shock would not be surprising. In fact, landslides and nontectonic surface cracks were observed northwest of Middle Mountain at the time of the 1966 Parkfield earthquake.

1922

The March 10, 1922, shock is the earliest Parkfield earthquake for which seismograms exist. Surface waves from the 1922 and 1934 shock recorded on the Bosch-Omori seismographs at the University of California, Berkeley, located 240 kilometers northwest of Parkfield, are very similar. Although a comparison of the Berkeley recordings implies that the 1922 epi-



Recordings of east-west component of motion from Galitzin instruments at De Bilt, the Netherlands. Comparison of seismograph recordings for 1922, 1934, and 1966 Parkfield earthquakes show close similarity of the shocks.

center was located 6 kilometers northwest of the 1934 epicenter, uncertainties in the arrival times of waves at Berkeley are such that the 1922 epicenter can only be constrained to an 18-kilometer-long section of fault immediately northwest of the 1934 epicenter. An oil pipeline (the Producers Transportation Line) which crosses the San Andreas fault near Cholame was broken in 1922 in three places (G.B. Moody, Chevron U.S.A., unpub. data, July 11, 1934). One of the breaks in 1922 was on at the fault trace, close to a 1934 break in a nearby oil pipeline.

The magnitude of $6\frac{1}{2}$ that was originally assigned to the 1922 main shock was based on 20-second period surface-wave measurements. Comparable measurements in 1966 yield a surface-wave magnitude of 6. More relevant is the comparison of 1922 surface waves recorded worldwide with those for the 1934 and 1966 shocks. The most reliable and convincing data, which were recorded at De Bilt, the Netherlands, imply that the seismic movement and surface-wave magnitudes for the 1922 and 1934 shocks are identical to within a precision of about 10Δ . There exist no 1-second-period data for the 1922 shock, and so no Richter magnitude estimate is possible.

1934

The June 8, 1934, earthquake poses several curious questions. Why did the timing of the 1934 shock violate the otherwise regular intervals of 21-22 years? Moreover, is the "early" occurrence of the 1934 shock related to the pronounced foreshock activity that occurred in 1934? Certainly, the 1934 foreshocks were dramatic, with two magnitude 5 shocks and 13 felt or located magnitude 3-4 shocks in the 67 hours before the main shock. All the well-located foreshocks were on the San Andreas fault just northwest of the main shock epicenter. One of the magnitude 5 foreshocks occurred 17 minutes before the main shock.

All the well-located aftershocks of the 1934 earth-

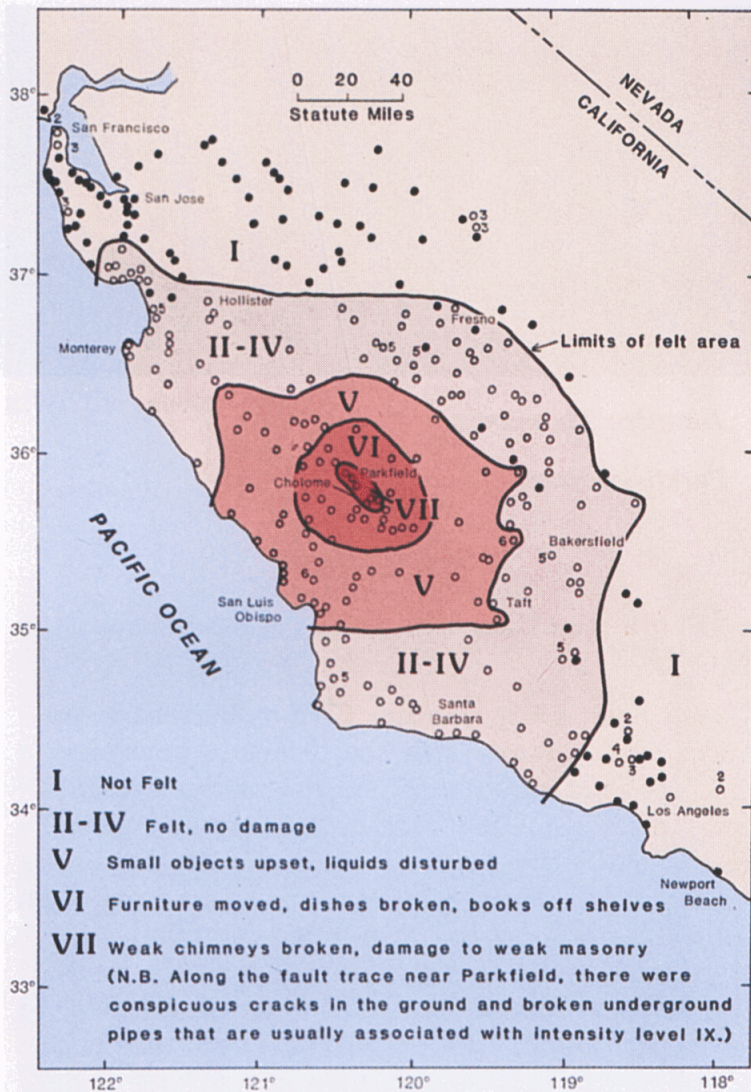
quake were on the San Andreas fault southeast of the main shock epicenter, which was located on Middle Mountain, suggesting that fault rupture during the main shock progressed from the northwest toward the southeast. Although the southeast end of the rupture is unknown, no located aftershocks occurred southeast of the offset in the fault trace that is located a few kilometers southeast of Gold Hill.

Another curious feature of the 1934 main shock is the pronounced difference in Richter magnitude obtained from recordings in southern and northern California. The magnitude assigned at the California Institute of Technology, using southern California recordings, is 6.0. In contrast, comparable recordings at seismographic stations operated in northern California by the University of California at Berkeley imply a Richter magnitude of 5.0. One explanation for this discrepancy is the southeast direction of rupture propagation suggested by the aftershocks' location—southeast of the main shock epicenter. Southeastward rupture should result in larger 1-second-period waves in southern California than in northern California, consistent with the measurements on which the Richter magnitude estimates for the 1934 main shock are based. Note that the Richter magnitude is an average of stations surrounding the epicenter, and so the magnitude for the 1934 main shock is closer to 5½ than the 6.0 that is often quoted. Because the surface waves generated by the 1934 main shock are nearly identical to those generated in 1922 and in 1966, the surface-wave magnitudes for the 1922, 1934, and 1966 main shocks are all approximately 6.

1966

As in 1934, a magnitude 5 foreshock occurred 17 minutes before the main shock on June 28, 1966; in all respects, the “17-minute” foreshocks in 1934 and in 1966 were virtually identical. In 1966 there were reports of anomalous surface deformation in the days before the earthquake, including an irrigation pipeline that broke and separated at the fault trace about 9 hours before the 1966 main shock, and fresh en echelon cracks of uncertain origin that were observed in the fault zone 12 days before the 1966 earthquake. One interpretation of the broken pipeline and the fresh cracks is that a few centimeters or more of slip occurred on the fault zone just before the 1966 shock.

As suggested for the 1934 event, rupture during the 1966 main shock began on Middle Mountain and propagated southeastward along the fault to near the offset in the fault trace southeast of Gold Hill. Also as in 1934, there is a discrepancy in the Richter magnitude



Modified Mercalli intensity pattern for the 1966 Parkfield earthquake. Pattern of shaking for the other significant Parkfield earthquakes is similar. Effects of shaking for anticipated Parkfield shock are expected to resemble this pattern as well.

from northern (5.5) and southern (5.8) California seismographs. The difference is not as large as in 1934, perhaps because of a slower speed of rupture in 1966 than in 1934. The average Richter magnitude for 1966 is 5.6, similar to the comparable average of $5\frac{1}{2}$ for the 1934 main shock. The surface-wave magnitude for the 1966 main shock is 6.0.



Middle Mountain, where the predicted earthquake is expected to begin.

Historical Vignettes of the 1881, 1901, 1922, 1934, and 1966 Parkfield Earthquakes*

Donalee Thomason

Parkfield, Rural Route

1881

From a Letter to the Editor in the *Salinas City Index*, February 4, 1881 (by "Z.T.")

"I left Salinas City January 23rd on horseback, up Long Valley to Peach Tree and thence to Imusdale [Parkfield's ancestral name] in Cholame Valley. On the 1st of this month we had seven shocks of earthquakes. The first were two very hard ones; they knocked down several chimneys, one adobe store room and one end of an adobe barn. I counted thirty quite large cracks in the ground running across the roads. It also opened several springs of water on Mr. P.'s [Parkinson's] ranch, one I noticed between the house and the road boiling up quite strong; just back of the house, it started sulphur springs and just where those sulphur springs are, the ground, about 20 paces square, is sunk about 4 feet."

1901

After the March 2, 1901, earthquake, a resident of the Cholame Valley, C.W. Wilson, wrote a letter to his family "Well Ma, we have had a terrible shaking up down here. Last night at 20 minutes of 12 o'clock there was the heaviest shock of earthquake I ever felt—my bed was jerked out in the middle of the floor, nearly all the goods in the store was on the floor in an instant and poor old Earth trembled and groaned like some person in great agony, and at intervals ever since has rumbled and shook. Daylight revealed a scene of destruction. All the chimneys in town were shaken down and the ground is seamed for miles they tell me. Half the people around seem half scared to

*Adapted from *Cholama—the Beautiful One, Cholame Valley History and its Pioneer People* by Donalee Thomason, Tabula Rasa Press, San Luis Obispo, California, 1988. Copies available from the author.

death. Lou Fisher was here this morning and said she felt 38 distinct shocks. And she like myself was not scared, only, as she said, it seemed queer to feel that what you had under you could not keep still”.

Mr. Buck Kester has experienced the last four Parkfield earthquakes. In the 1901 shake he was not quite three years old, but Kester has a great memory, and he can vaguely remember standing near Lang Canyon where several men were rebuilding their fireplaces after the quake.



1922

The next notable earthquake came in 1922. Buck was working for Ben Carr, plowing with a ten horse team. The Carr house sits right on the San Andreas fault. As Buck recalls, the shake arrived at around 3 a.m. Buck said he could hear dead limbs falling off the cottonwood trees, also the Carr children screaming from fright. He relates that a tramp had come the night before and had asked to sleep in the barn. The next morning the horses had stampeded and were gone from the barn—so was the tramp!

Evelyn Fretwell Carr tells a story about Buck and the 1922 quake. It seems he was sleeping in a little room attached to the Carr house. The next day Buck made the remark, “I needed spurs to ride the bed.” Kester had said that he feels the 1922 quake was not as strong as the 1966 shock.

Oak Street in Parkfield in 1912, showing stores, a hotel, and other commercial establishments. The much smaller Parkfield of today has no public accommodations or facilities. Photograph courtesy of Donalee Thomason.



Parkfield elementary school is one of 12 operational one-room elementary schools in California. After school, Duane Hamann, the teacher, operates the two-color laser geodimeter as part of the earthquake prediction experiment. Photograph courtesy of Tom Burdette.

1934

The author describes the 1934 and 1966 shocks from first-hand experience.

“On June 7*, my mother was in charge of an end of the school year program on the stage at the old Parkfield Community Hall. I was nine years old at the time. The program was in progress around 8 p.m., when the fairly heavy foreshock arrived. The program came to a halt for several minutes. Someone in the audience said, ‘The big one always comes first, let’s get on with the play.’ So the program went on. However, in about 17 minutes the person that spoke up was proven wrong. The main earthquake arrived with a vengeance.

I remember being thrown back and forth against the walls of the narrow runway behind the stage. It seemed the hall was turning upside down there in the darkness for a few seconds. I could hear people screaming and trying to run to the exit, falling down of course. The program came to a halt for the second time that evening. People stood around this time discussing what they should do. It was decided that the show must go on!

*The shock occurred on June 7, 1934, Pacific standard time; however, scientists use the Greenwich civil time date, June 8, 1934.

Little aftershocks kept arriving. By now we were all out on the stage, and kept in a panic by these little unwelcome shocks. I've often wondered how we completed the program, and I've also wondered if that earthquake happened just to celebrate my mother's last day to teach in Parkfield."

1966

"Between 8:00 and 9:00 p.m. on a hot Monday evening in June the heavy foreshock arrived, and there was no rumble. The very first thing my ears recorded was similar to a great drawing in of a breath, or a suction sound may be a better description. Then a blast of hot air hit my back as the shock wave rushed through.

I tried to hang onto the door frame. I looked toward the ceiling in the kitchen. To this day I do not see how walls could have buckled that much and then snapped back into place. Dust was flying everywhere.

What I didn't see was the door coming straight at me from the right; it hit me hard enough to knock me down on one knee, but I kept trying to see and record in my mind what was happening. Looking at the china cabinet, I was shocked to see its latched doors burst open as the wall buckled. The colored glassware shot straight out of the cabinet and stood in mid-air. After a few seconds all the pieces crashed and shattered on the kitchen floor. What a noise all this made, what with both fireplaces going down and boards popping and cracking, and items falling and breaking all over the house. I glanced at the floor and felt immediate motion sickness. At this time the electricity went off and everything was dark, but the noise continued.

After the earthquake that night, my husband and I slept in our car. It rolled back and forth most of the night as the many aftershocks kept coming. My son elected to sleep in his bed but the next morning he said that he had to hang onto the headboard most of the night. One family said later that during the day before the big earthquake, their dog hung under their feet all day; he made such a pest of himself they had to tie him up to keep from tripping over him."

The Role of the Federal Government in the Parkfield Earthquake Prediction Experiment

John R. Filson
U.S. Geological Survey
Reston, Virginia

Earthquake prediction research in the United States is carried out under the aegis of the National Earthquake Hazards Reduction Act of 1977. One of the objectives of that act is "the implementation in all areas of high or moderate seismic risk, of a system (including personnel and procedures) for predicting damaging earthquakes and for identifying, evaluating, and accurately characterizing seismic hazards." Among the four Federal agencies working under the 1977 act, the U.S. Geological Survey (USGS) is responsible for earthquake prediction research and technological implementation. The USGS has adopted a goal that is stated quite simply: predict the time, place, and magnitude of damaging earthquakes. The Parkfield earthquake prediction experiment represents the most concentrated and visible effort to date to test progress toward this goal.

The initial approach to earthquake prediction by the USGS beginning in 1978 was to measure physical parameters in areas where earthquakes occur. These parameters included seismicity, strain, water levels and water chemistry, heat flow, geomagnetism, electrical potential and conductivity, seismic velocities, and animal behavior. During these early years, the scientists involved were experts in their field whose efforts might be described as individual reconnaissance studies rather than a coordinated approach to earthquake prediction. While some prediction effort is still in individual reconnaissance, research has developed into an integrated, multifaceted program at Parkfield.

In the late 1970's, two significant reports on earthquake prediction were published. The first, in 1978, by Allan Lindh of the USGS described, in a routine report of work in progress, the Parkfield Prediction project, a small research effort consisting of four people. The second, in 1979, was by William Bakun of the USGS and Thomas McEvilly of the University of California at Berkeley entitled "Earthquakes near Parkfield, California: Comparing the 1934 and 1966 Sequences." Bakun and McEvilly developed the concept of similar, periodically recurring earthquakes at Parkfield and pointed out that earthquakes in the region in 1901 and 1922 were similar to the



In 1984, then Secretary of the Interior William Clark (at left, with Mrs. Clark to his left) reviewed USGS facilities at Parkfield along with USGS scientists.

1934 and 1966 shocks. Lindh's project established the first federally funded, coordinated earthquake prediction experiment in the Parkfield region; Bakun and McEvelly's report laid the groundwork for the formal prediction that would eventually be made some 6 years later. Perhaps the most significant piece of this synergy was that Lindh, based on his knowledge of Bakun and McEvelly's work, knew the parameters of the earthquake that he was trying to predict.

During reauthorization hearings for the Earthquake Hazards Reduction Act in the spring of 1982, Senator Harrison Schmitt, Chairman of the Senate Sub-Committee on Science, Technology, and Space, expressed concern that the USGS was not moving aggressively toward an operational earthquake prediction system. In a hearing dealing with programs in the National Oceanic and Atmospheric Administration (NOAA), he suggested that NOAA with "the tradition of (weather) forecasting, might be the appropriate lead agency for earthquake hazards prediction and mitigation." In September of 1982, in a letter to Dallas Peck, Director of the USGS, Senator Schmitt stated "I feel strongly that some type of prototype earthquake prediction system needs to be in place in the United States within four to five years. Such a system could provide short-term warning of an impending major earthquake as well as providing invaluable data for predicting subsequent major shakes and for better understanding the precursors to earthquakes." In the meantime, Lindh was continuing his limited effort to record and interpret geophysical data from the Parkfield area, and Bakun and McEvelly searched for further evidence of earlier earthquakes in the region and information on their characteristics. The broader USGS program of earthquake prediction research continued with theoretical and laboratory studies and fieldwork in other areas of California and elsewhere.

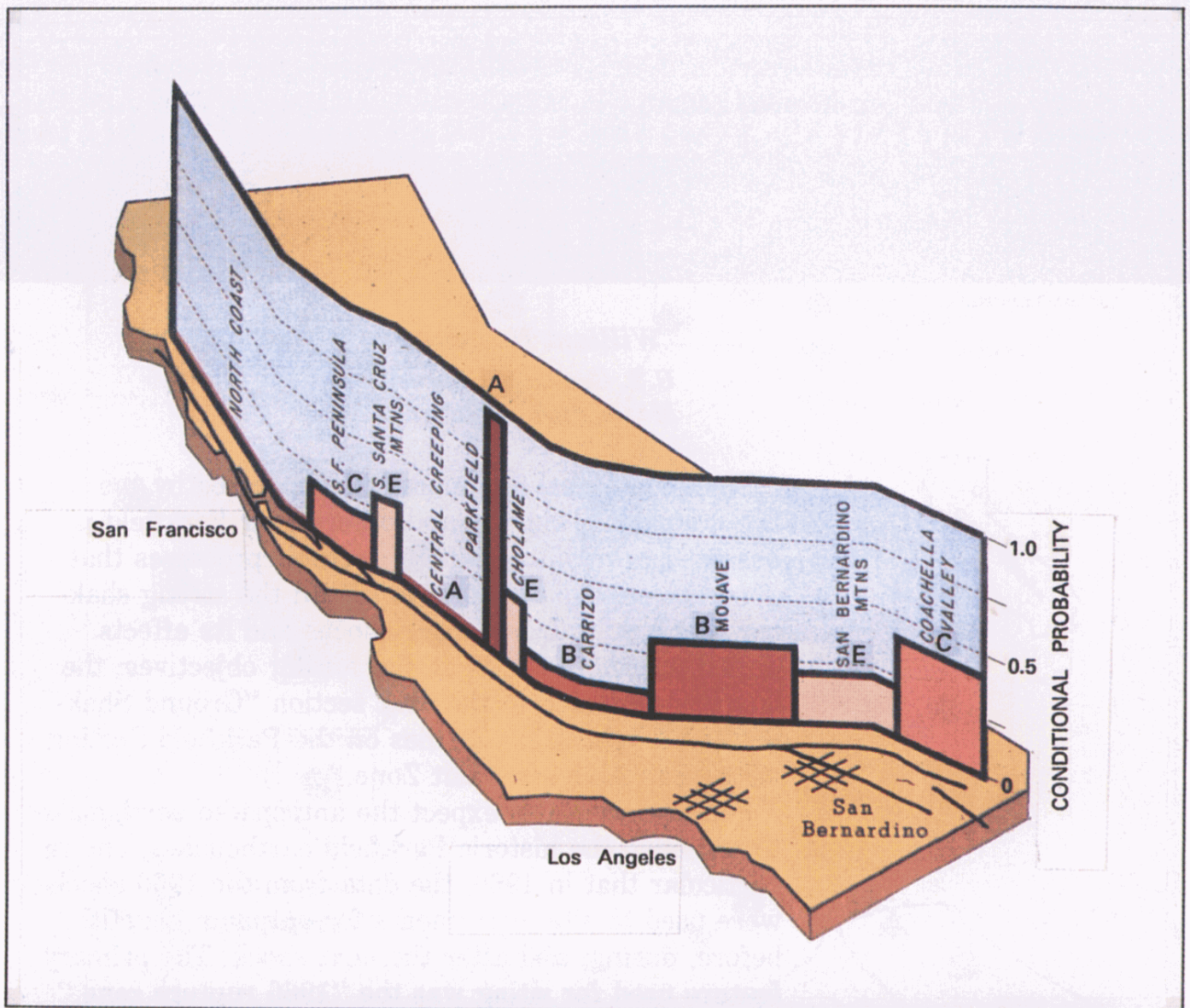
In 1983, in response to Senator Schmitt's concern, James Dieterich, the USGS program manager for earthquake predic-

tion at the time, published a report entitled "Assessment of a Prototype Earthquake Prediction Network for Southern California." Dieterich's approach placed clusters of densely spaced geophysical instruments in locations where geologic evidence suggested that an earthquake might be imminent. Data from these instrumentation clusters would be monitored continuously and results made available almost simultaneously. The cluster approach had the advantage of focusing attention on a particular segment of an active fault and of bringing many types of data to bear on the prediction problem. It required foreknowledge of the earthquake to be predicted and forced an interdisciplinary assessment of the many different types of measurements.

In 1984 there were several new developments. Bakun and McEvilly published evidence for significant earthquakes at Parkfield occurring every 22 years. Furthermore, they predicted that the next earthquake in the sequence of characteristic earthquakes should occur in the 1983-93 time interval. In the same year William Clark, then Secretary of the Interior, charged the USGS with developing a plan for a prototype earthquake prediction system in southern California. The USGS plan involved a number of options based on Dieterich's cluster concept that were discussed by the National Academy of Sciences and the Seismic Safety Commission of the State of California. One unanticipated result of this latter discussion was the introduction of State legislation to provide \$1 million of State funds to help purchase instrumentation for a cluster at Parkfield, provided a matching Federal sum was designated for the same purpose. On the scientific front, Lindh presented the USGS assessment of earthquake hazard at Parkfield to the National Earthquake Prediction Evaluation Council. The Chairman of this Council, Lynn Sykes of Lamont-Doherty Geological Observatory (Columbia University), conveyed to the Director of the USGS the Council's endorsement of the USGS prediction of an event of about magnitude 6 to occur in the Parkfield region in 1988 ± 5 years. In April 1985 the Director of the USGS formally advised William Medigovich, Director of the California Office of Emergency Services, of the prediction. Furthermore, the USGS Director obligated the USGS to attempt to issue a short-term warning—to the extent that such a warning might be possible—of the expected earthquake.

Today, data from Parkfield are monitored continuously at the USGS Western Region headquarters in Menlo Park, California, and certain USGS scientists carry electronic pagers that are triggered by computers that scan the incoming data flow. The new equipment purchased under the joint State-Federal funding agreement is operational, and a Parkfield Working Group meets monthly at Menlo Park to review the status of the Parkfield experiments.

When asked recently to prepare a draft statement announcing a successful short-term earthquake warning at Parkfield, I was reminded that General Eisenhower had two press releases



Probability for occurrence of major earthquakes along the San Andreas fault 1988-2018 (The Working Group on California Earthquake Probabilities, 1988). Probability values are based on knowledge of the time that has elapsed in the earthquake cycle without significant seismic activity. The reliability represents the Working Group's subjective confidence in each probability estimate and is based in part on the type and quality of the data used (A is highest reliability, E is lowest; no segments of the San Andreas fault were assigned to reliability level D.). The probability assigned to the Parkfield section, more than 0.9 with level-A reliability, is the highest, reflecting the prediction of a significant earthquake before 1993.

prepared for D-Day. One announced that a successful beach-head had been established, the other that the Allied armies had been repulsed. Although the USGS is making a concerted effort to issue a short-term warning of the next Parkfield earthquake, it must be recognized that such warnings may simply not be possible. Nonetheless, the Parkfield experiment is a crucial test for earthquake prediction in central California.

Geophysical Instrumentation Near Parkfield

William H. Bakun
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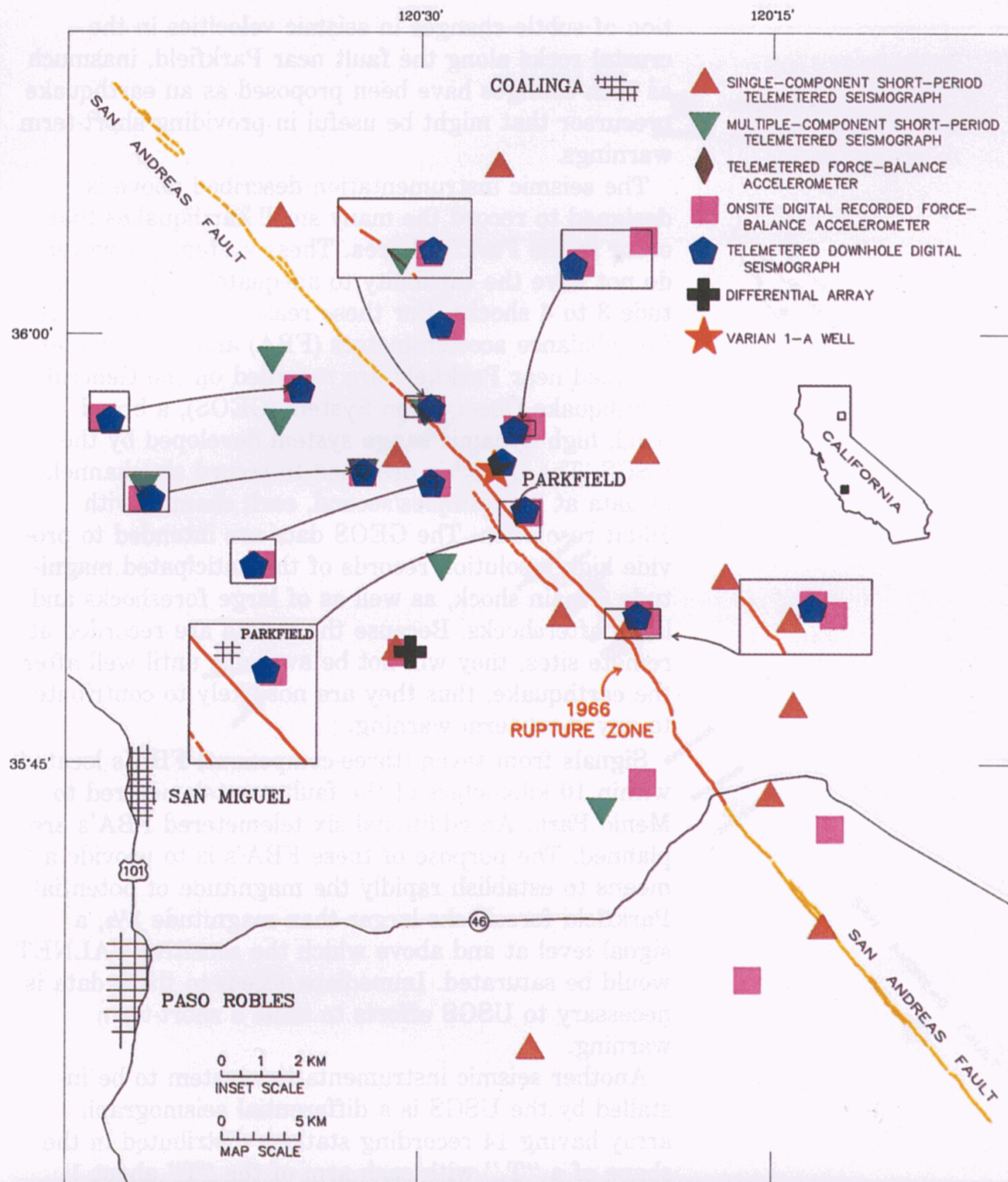
The geophysical instrumentation operated by the U.S. Geological Survey and others near Parkfield is designed to monitor ongoing tectonic processes that generate earthquakes and to record the strong shaking that results from larger shocks and its effects. This discussion focuses on the former objectives; the latter is discussed in the next section "Ground Shaking and Engineering Studies on the Parkfield Section of the San Andreas Fault Zone."

Because scientists expect the anticipated earthquake to resemble the historic Parkfield earthquakes, and in particular that in 1966, the data from the 1966 shock were used to site instruments for optimum benefit before, during, and after the next shock. The primary feature used for siting was the "1966 rupture zone," which is shown as the orange fault traces on the maps in this section. This zone defines the extent of surface tectonic cracks in 1966 and includes the source areas for foreshocks to the 1934 and 1966 earthquakes (north end of the zone) as well as for apparent precursory fault creep in 1966 (near center of the zone). Scientists believe that if precursors to the next shock are observed, they most likely will be near the 1966 rupture zone.

Seismicity

Currently there are 18 high-gain, short-period, vertical-component Central California Seismic Network (CALNET) seismometers located within 25 kilometers of the town of Parkfield; 6 of these sites record horizontal components as well. Data from CALNET are continuously telemetered to the USGS center in Menlo Park. There, a real-time processor provides estimates of earthquake locations and magnitudes within 3 to 5 minutes of their occurrence for shocks as small as magnitude 0.8.

In addition, three-component seismometers have been installed in boreholes near Parkfield in cooperation with the University of California at Santa Bar-



Seismographs and accelerometers located near Parkfield as of October 1987. Fault is dashed where uncertain or unknown.

bara (UCSB) and the University of California at Berkeley (UCB). They provide high-gain, high-frequency seismic information for magnitude -0.25 and larger shocks, a sensitivity level not obtainable from the CALNET seismographs. A digital radio telemetry system (500 samples/second, 16-bit resolution) is used to record the borehole seismographs at a central site. Also, 116 seismometers and accelerometers have been deployed by UCB and UCSB in a $1\frac{1}{2}$ -kilometer-deep well (the Varian 1-A well) near the fault. A surface vibrator (VIBROSEIS) is used by UCB as a source of seismic energy for an investiga-

tion of subtle changes in seismic velocities in the crustal rocks along the fault near Parkfield, inasmuch as such changes have been proposed as an earthquake precursor that might be useful in providing short-term warnings.

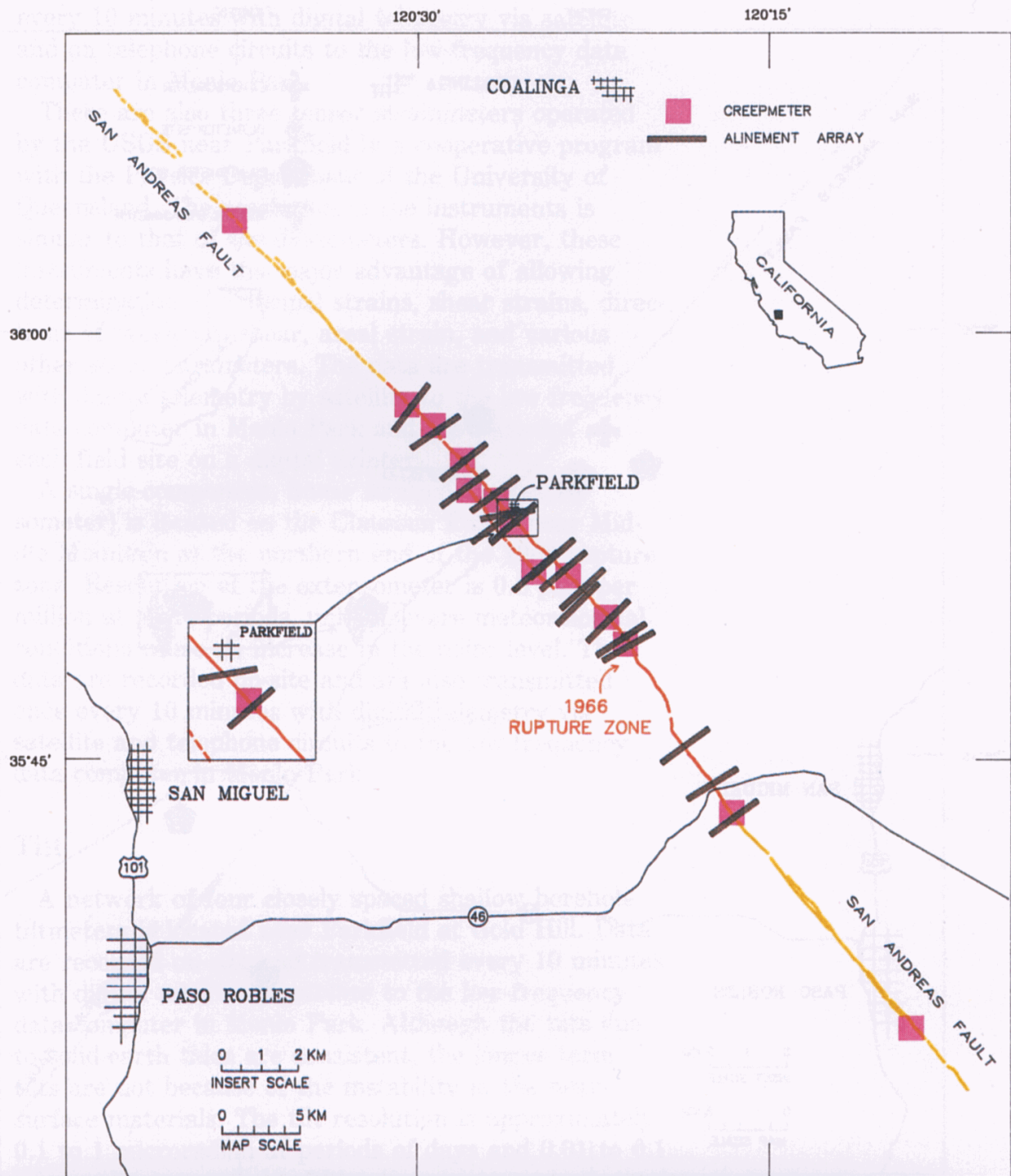
The seismic instrumentation described above is designed to record the many small earthquakes that occur in the Parkfield area. These systems, however, do not have the capability to adequately record magnitude 3 to 4 shocks. For these reasons, an array of 14 force-balance accelerometers (FBA) and seismometers installed near Parkfield are recorded on the General Earthquake Observation System (GEOS), a broadband, high dynamic range system developed by the USGS. The GEOS is designed to record six channels of data at 200 samples/second, each channel with 16-bit resolution. The GEOS data are intended to provide high-resolution records of the anticipated magnitude 6 main shock, as well as of large foreshocks and large aftershocks. Because these data are recorded at remote sites, they will not be available until well after the earthquake; thus they are not likely to contribute to any short-term warning.

Signals from seven (three-component) FBA's located within 10 kilometers of the fault are telemetered to Menlo Park. An additional six telemetered FBA's are planned. The purpose of these FBA's is to provide a means to establish rapidly the magnitude of potential Parkfield foreshocks larger than magnitude $3\frac{1}{2}$, a signal level at and above which the sensitive CALNET would be saturated. Immediate access to these data is necessary to USGS efforts to issue a short-term warning.

Another seismic instrumentation system to be installed by the USGS is a differential seismograph array having 14 recording stations distributed in the shape of a "T," with each arm of the "T" about 1 kilometer long. The array, designed to record data useful for both earthquake prediction and strong-motion studies, will be used to study (1) wave propagation of seismic energy from small shocks in the Parkfield area and (2) rupture along the fault during the anticipated main shock.

Creep

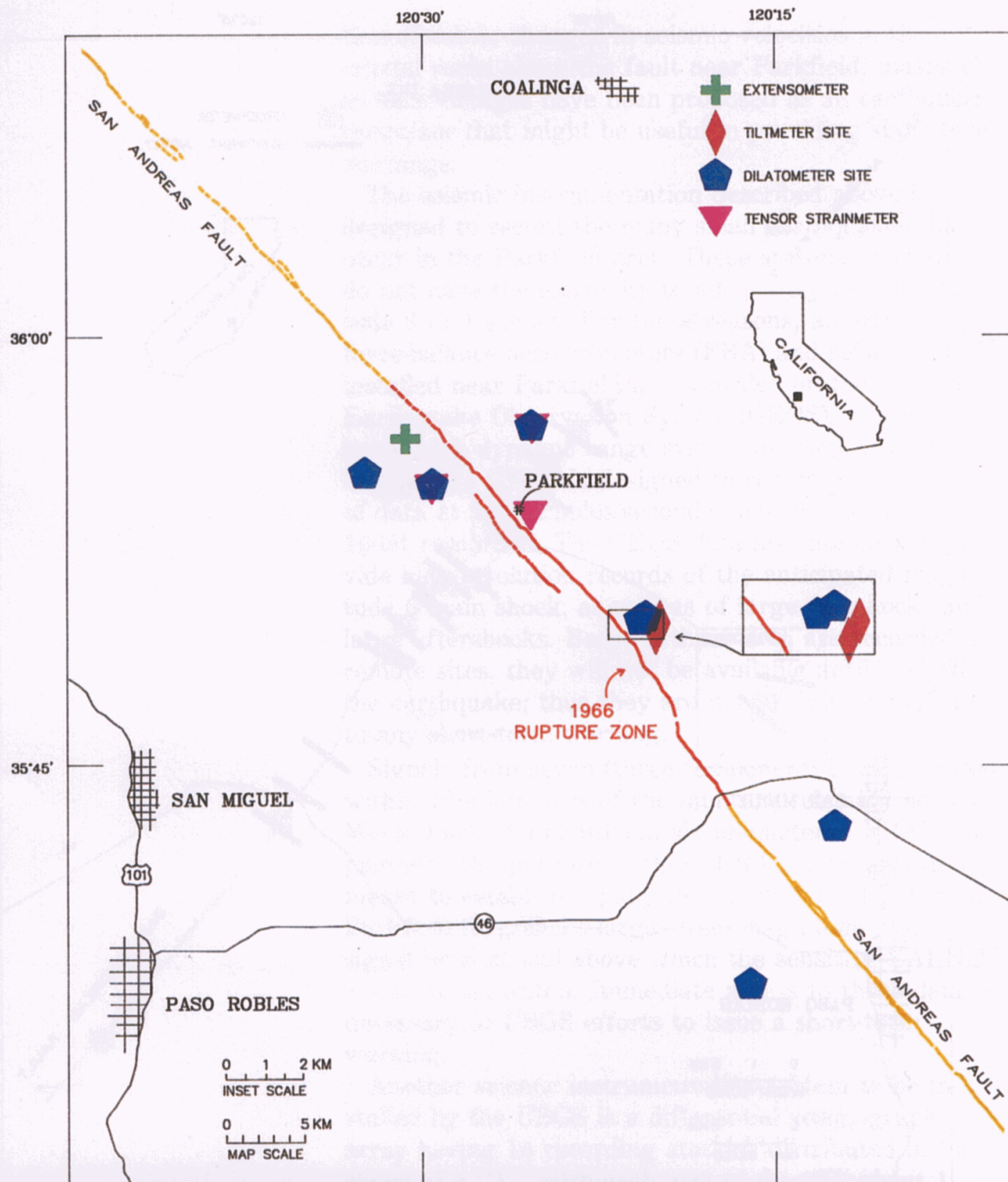
The 13 creepmeters in the Parkfield area relay data showing surface slip on the fault to Menlo Park every 10 minutes via satellite and telephone telemetry. The Middle Mountain creepmeter is located in the epicentral region of past Parkfield main shocks and foreshocks and of the anticipated Parkfield main shock.



Creepmeters and alignment arrays located near Parkfield as of October 1988. Fault is dashed where uncertain or unknown.

Eleven of the creepmeters are invar-wire instruments with 0.02 millimeter resolution, and two are invar-rod instruments with 0.05-millimeter resolution.

The 19 alignment arrays are 30- to 200-meter-long survey lines that are measured periodically to determine the local slip rate, the width of the slip zones, and patterns of deformation near the fault trace at Parkfield. Some of these arrays have been surveyed since shortly after the 1966 earthquake.



Strainmeters and tiltmeters located near Parkfield as of October 1987. Fault is dashed where uncertain or unknown.

Strain

To monitor deformation in the crust near the fault, a variety of strainmeters is used. The seven Sacks-Evertson borehole volumetric strainmeters (dilatometers) near Parkfield are operated by the USGS in cooperative effort with the Carnegie Institution of Washington. The resolution of the dilatometers ranges from 10^{-2} part per million for signals with periods of several weeks to 10^{-5} part per million for much shorter periods. The data are recorded on-site by GEOS at two gain levels and are transmitted once

every 10 minutes with digital telemetry via satellite and on telephone circuits to the low-frequency data computer in Menlo Park.

There are also three tensor strainmeters operated by the USGS near Parkfield in a cooperative program with the Physics Department of the University of Queensland. The resolution of the instruments is similar to that of the dilatometers. However, these instruments have the major advantage of allowing determination of principal strains, shear strains, directions of maximum shear, areal strain, and various other strain parameters. The data are transmitted with digital telemetry by satellite to the low-frequency data computer in Menlo Park and are recorded at each field site on a digital printer.

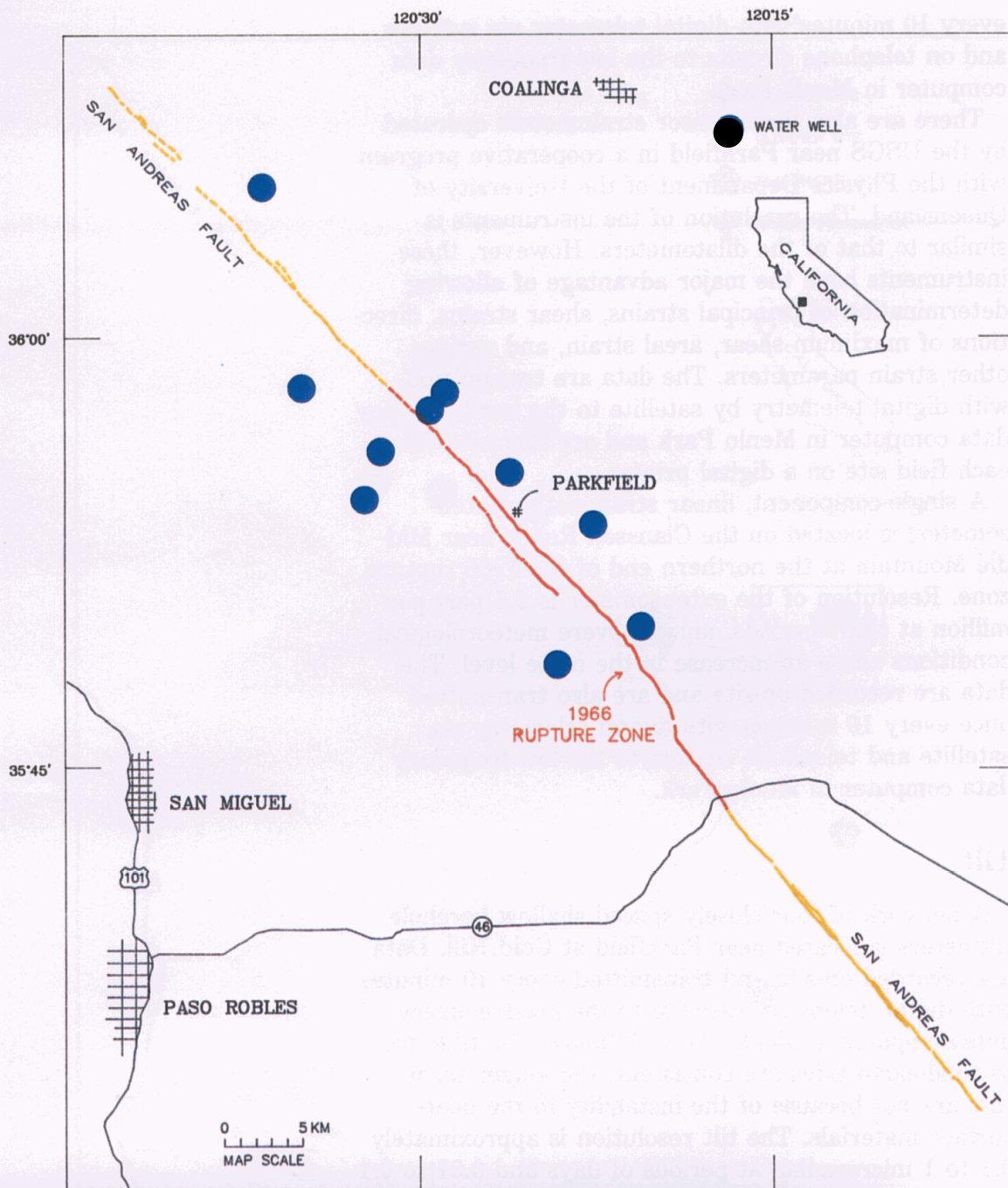
A single-component, linear strainmeter (extensometer) is located on the Claussen Ranch near Middle Mountain at the northern end of the 1966 rupture zone. Resolution of the extensometer is 0.5 part per million at short periods, unless severe meteorological conditions cause an increase in the noise level. The data are recorded on-site and are also transmitted once every 10 minutes with digital telemetry via satellite and telephone circuits to the low-frequency data computer in Menlo Park.

Tilt

A network of four closely spaced shallow borehole tiltmeters is located near Parkfield at Gold Hill. Data are recorded on-site and transmitted every 10 minutes with digital telemetry satellite to the low-frequency data computer in Menlo Park. Although the tilts due to solid-earth tides are consistent, the longer term tilts are not because of the instability in the near-surface materials. The tilt resolution is approximately 0.1 to 1 microradian at periods of days and 0.01 to 0.1 microradian at periods of hours.

Water Wells

Fluctuation of ground-water levels in a network of wells near Parkfield is being monitored by the USGS as another method of determining deformation near the fault. Eighteen wells have been installed at 13 sites. Fourteen wells are completed in relatively deep, confined aquifers, and four monitor shallow water-table aquifers. At Middle Mountain and Joaquin Canyon dual-completion wells monitor two separate, confined or semiconfined depth intervals at each site. In addition, two unused stock wells in Hog Canyon are equipped with analog recorders. At 12 sites water levels are sampled every 15 minutes, and accumulated



Water wells monitored near Parkfield as of October 1987. Fault is dashed where uncertain or unknown.

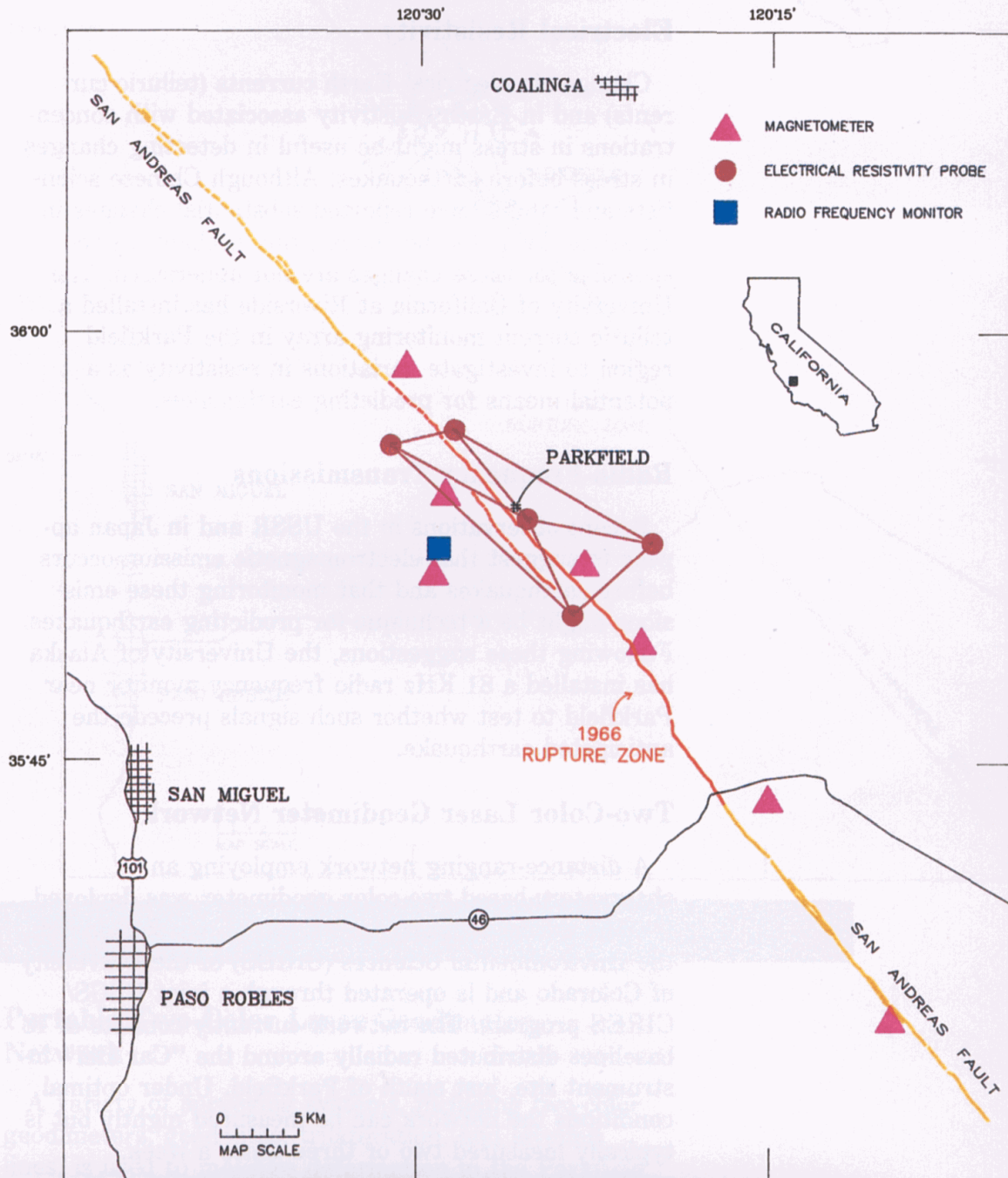
data are transmitted every 4 hours via satellite to the low-frequency data computer in Menlo Park. Data are also transmitted to a computer in Menlo Park via a receiver site in Phoenix. Satellite telemetry from one more site is expected to be added soon. At periods of 2 weeks or less, water levels respond to the local volume strain, so the water-level changes can be directly compared to dilatometer data. Eight of the wells on satellite telemetry record unambiguous solid-earth tides, indicating that their sensitivities at periods of days are at least 0.01 part per million.

In addition, plans to monitor the pore-pressure fluc-

tuations and variations in temperature in the over-pressured zone at the bottom of the Varian 1-A well are being developed. The proximity of the well not only to the fault, but also to the expected epicenter of the anticipated magnitude 6 shock, suggests that data from this well might prove critical in understanding the processes leading to the predicted Parkfield earthquake.

Magnetic Field

Local magnetic fields are monitored with absolute



Magnetoelectric monitor sites near Parkfield as of October 1988. Fault is dashed where uncertain or unknown.

total field magnetometers at seven sites in the Parkfield region in order to detect changes in the Earth's magnetic field due to stress changes within the crust. The data are synchronized to within 1.0 second and are transmitted with 16-bit digital telemetry by satellite to Menlo Park. The measurement precision in the period of 10 minutes to tens of days is approximately 0.2 to 0.7 nanotesla, respectively. Changes of 1.0 nanotesla corresponding to stress changes of several bars can, according to current models, be detected with the present instrumentation at periods greater than a day.

Electrical Resistivity

Changes in electrical Earth currents (telluric currents) and in Earth resistivity associated with concentrations in stress might be useful in detecting changes in stress before earthquakes. Although Chinese scientists and others have reported substantial changes in resistivity before some shocks, the mechanisms responsible for these changes are not understood. The University of California at Riverside has installed a telluric current monitoring array in the Parkfield region to investigate variations in resistivity as a potential means for predicting earthquakes.

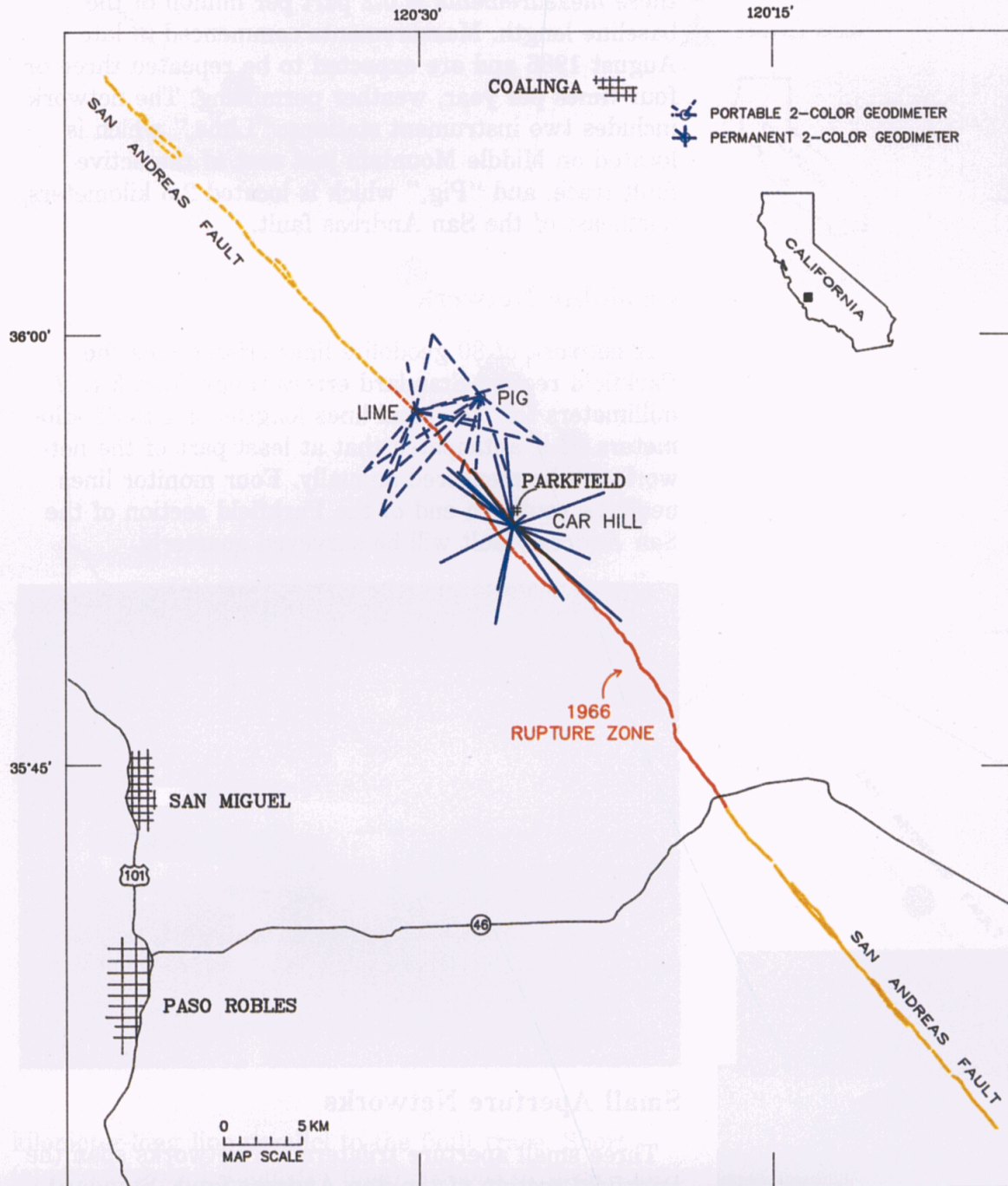
Radio-Frequency Transmissions

Recent observations in the USSR and in Japan appear to suggest that electromagnetic emission occurs before earthquakes and that monitoring these emissions might be a technique for predicting earthquakes. Following these suggestions, the University of Alaska has installed a 81 KHz radio frequency monitor near Parkfield to test whether such signals precede the anticipated earthquake.

Two-Color Laser Geodimeter Network

A distance-ranging network employing an observatory-based two-color geodimeter was deployed in 1984 by the Cooperative Institution for Research in the Environmental Sciences (CIRES) of the University of Colorado and is operated through a joint USGS/CIRES program. The network currently consists of 18 baselines distributed radially around the "Car Hill" instrument site, just south of Parkfield. Under optimal conditions the network can be measured nightly but is typically measured two or three times a week, weather permitting. Typical standard errors of individual measurements are 0.5 to 0.7 millimeter for 4 to 6 kilometers of line lengths. Eleven of the lines

were installed and the lengths measured by October 1984. The full 18-line network was completed on July 31, 1986.



Two-color laser geodimeter networks near Parkfield as of October 1987. Fault is dashed where uncertain or unknown.

Portable Two-Color Laser Geodimeter Network

A variety of surveying systems, including two-color geodimeters, geodolites, trilateration, and leveling lines, is used to measure deformation in the Parkfield region at scales from a few hundred meters to tens of kilometers. A distance-ranging network consisting of

20 baselines that span the Middle Mountain section of the San Andreas fault provides a measure of surface and shallow slip near Middle Mountain. Precision of these measurements is 0.2 part per million of the baseline length. Measurements commenced in late August 1986 and are expected to be repeated three or four times per year, weather permitting. The network includes two instrument stations: "Lime," which is located on Middle Mountain just east of the active fault trace, and "Pig," which is located 2.5 kilometers northeast of the San Andreas fault.

Geodolite Network

A network of 80 geodolite lines crisscrosses the Parkfield region. Standard errors range from 3 to 7 millimeters for individual lines lengths of 4 to 33 kilometers. It is anticipated that at least part of the network will be measured annually. Four monitor lines near the southern end of the Parkfield section of the San Andreas fault will be surveyed quarterly.



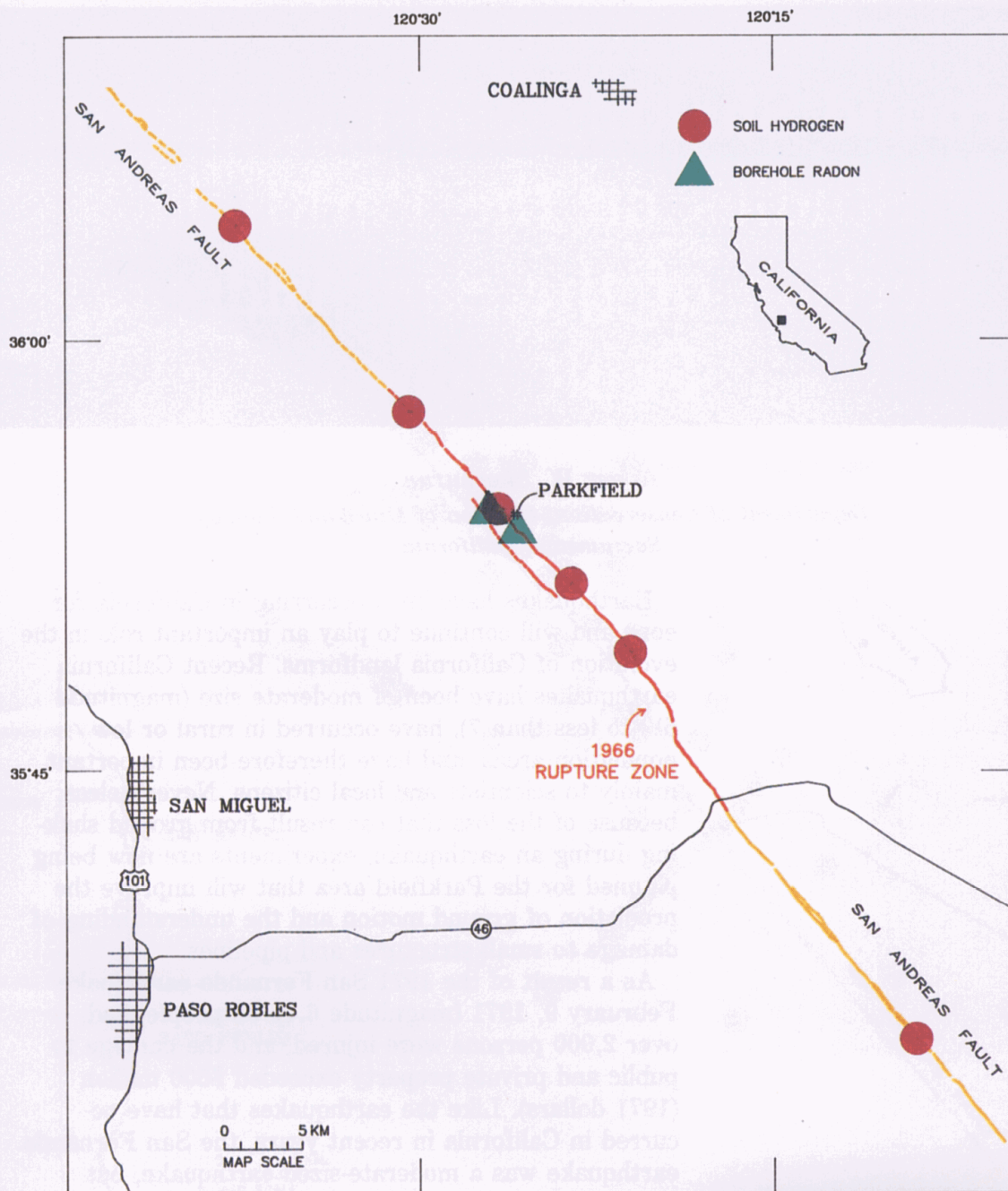
USGS scientist operates two-color laser geodimeter at Car Hill station near Parkfield.

Small Aperture Networks

Three small aperture trilateration networks span the Parkfield section of the San Andreas fault. Standard errors for individual measurements are 4 millimeters. Thirty-one near-fault lines are scheduled to be surveyed quarterly.

Leveling Network

A network of leveling lines in the Parkfield region has been periodically surveyed since 1979. The network consists of four lines: a 10-kilometer-long line perpendicular to the fault at Parkfield, a 32-kilometer-long line in the vicinity of Middle Mountain, a 17-kilometer-long line perpendicular to the fault at the southern end of the 1966 rupture zone, and a 24-



Geochemistry monitor sites near Parkfield as of October 1988. Fault is dashed where unknown or uncertain.

kilometer-long line parallel to the fault trace. Short (approximately 1 kilometer long) sections of these long lines are surveyed 3 to 4 times a year in a joint effort with the University of California at Santa Barbara.

Geochemistry

Although certain geochemical data have been reported to show anomalous changes before earthquakes, the mechanisms responsible for these changes are not understood. Radon gas and hydrogen gas in the soil are now monitored near Parkfield. In addition, continuous radon and hydrogen monitors have been installed in one 400-foot-deep water well in the fault zone near Parkfield; water samples from this well will be collected periodically for chemical analysis.

Ground Shaking and Engineering Studies on the Parkfield Section of the San Andreas Fault Zone

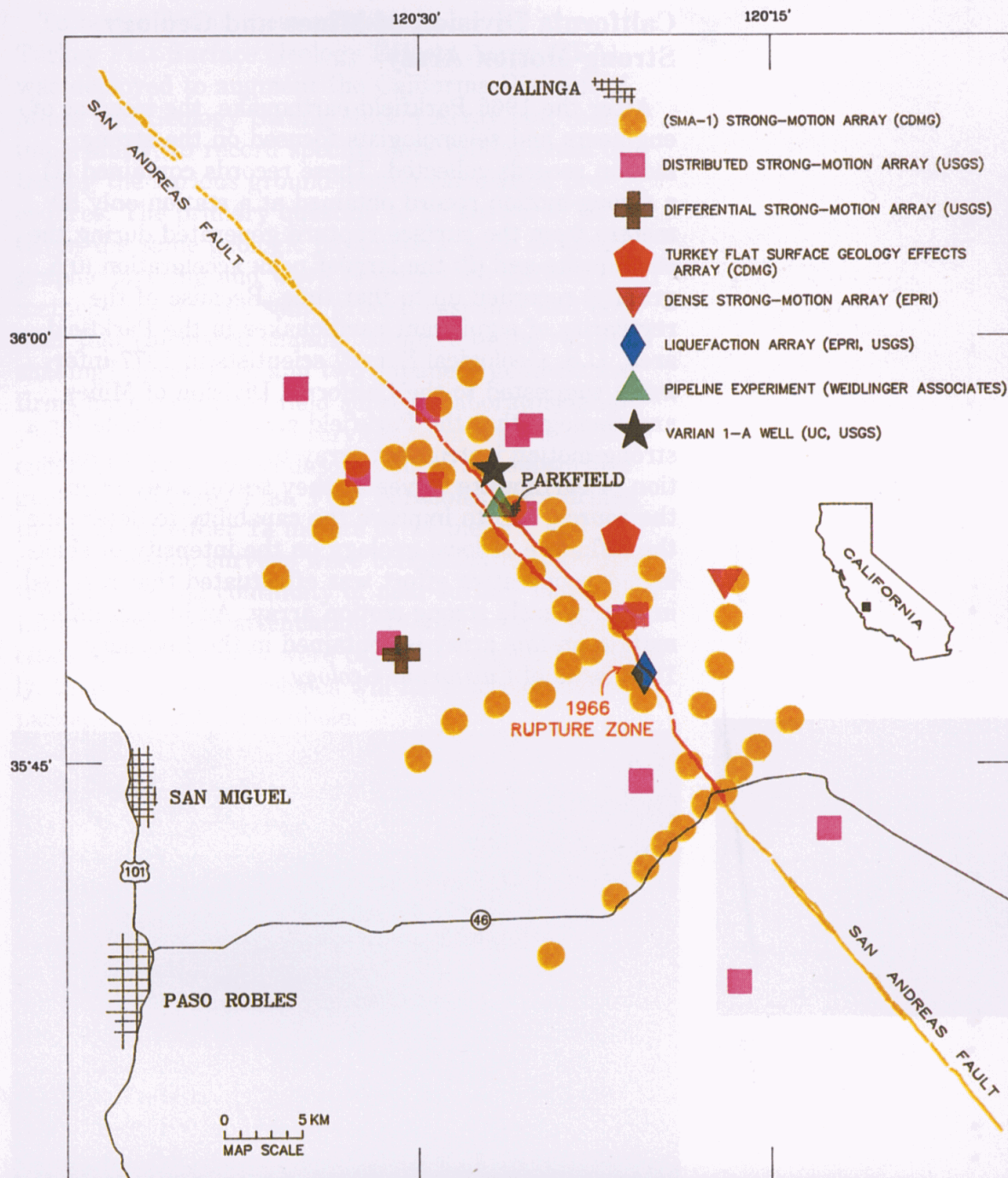
Roger W. Sherburne

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Earthquakes have been occurring in California for eons and will continue to play an important role in the evolution of California landforms. Recent California earthquakes have been of moderate size (magnitude $5\frac{1}{2}$ to less than 7), have occurred in rural or low population areas, and have therefore been important mainly to scientists and local citizens. Nevertheless, because of the loss that can result from ground shaking during an earthquake, experiments are now being planned for the Parkfield area that will improve the prediction of ground motion and the understanding of damage to small structures and pipelines.

As a result of the 1971 San Fernando earthquake February 9, 1971 (magnitude 6.4), 58 people died, over 2,000 persons were injured, and the damage to public and private property exceeded \$500 million (1971 dollars). Like the earthquakes that have occurred in California in recent years, the San Fernando earthquake was a moderate-sized earthquake, but unlike all but one of the other shocks, which occurred in rural areas, it occurred near an urbanized area. As a result of the San Fernando earthquake, it became evident to engineers, scientists, and officials of State government that to improve seismic safety, data were needed about how the ground and engineered structures responded, singularly and in unison, to the passage of earthquake waves. These data could only be derived from the actual (rather than theoretical) analysis of shaking data collected from existing structures during earthquakes.

If the approximate time and location of a damaging earthquake could be known in advance, then the needed shaking data could be collected economically. Normally, this predictive information is not available; however, the Parkfield experiment has presented the opportunity for well-planned data collection. Conse-



Strong-ground-motion and engineering instrumentation sites near Parkfield as of October 1987. The distributed and differential strong-motion arrays as well as the Varian 1-A borehole have associated earthquake prediction instrumentation and are described in the chapter "Geophysical Instrumentation near Parkfield." See text for agency abbreviations.

quently, various projects are being conducted to collect data necessary to better understand strong ground motion and structural response to it. This article describes Parkfield's strong motion experiments, which are of particular interest to earthquake engineers; instrumentation described in the previous section "Geophysical Instrumentation near Parkfield" is not repeated here.

California Division of Mines and Geology Strong-Motion Array

After the 1966 Parkfield earthquake, the interest of engineers and seismologists focused on the strong-motion records collected. These records contained (1) a strong-motion record obtained at a station only 80 meters from the surface rupture generated during the earthquake and (2) the largest peak acceleration (0.5 gravity) recorded up to that time. Because of the regularity of significant earthquakes in the Parkfield area, U.S. Geological Survey scientists in 1977 informally suggested to the California Division of Mines and Geology that the Parkfield area was suitable for a strong-motion instrument array to study the attenuation of earthquake waves as they travel away from the source, and to improve the capability to determine the influence of local geology on the intensity of shaking. A cooperative effort was effectuated that resulted in a large-scale strong-motion array. Additional information on this array is contained in the February 1983 issue of *California Geology*.

Typical California Division of Mines and Geology strong-ground-motion recording station in the Parkfield area. A solar panel on the back side of the housing supplies the electrical power to operate the recorder within the instrument housing.



Turkey Flat Surface Geology Array

Because numerous manmade structures, including dams and hospitals, are located in areas where there is insufficient knowledge about earthquake history and tectonic movement, engineers and seismologists strive to predict the expectable ground motion to be expected at such sites. Ground-motion prediction is then incorporated into seismic risk evaluations and into the design of new structures. These ground-motion predictions, incorporating detailed calculations, invariably require certain geologic assumptions and, moreover, are based on methods of calculation that have not been adequately tested.

To better define these methods, a second array, the Turkey Flat Surface Geology Effects Array (TFA), was deployed to augment the California Division of Mines and Geology Strong-Motion Array but, more importantly, to record specific data fundamental to testing the various ground-motion calculation procedures. The primary question to be answered is: Given the same geologic parameters, such as stratigraphic layering and wave velocities, do different methods predict the same ground response and how does that calculated shaking compare to the recorded shaking? Seven U.S. and two Japanese geotechnical firms have conducted field surveys, laboratory analyses, and interpretative services to provide a highly coherent and accurate description of the subsurface geology at Turkey Flat. Four boreholes were drilled to depths of either 12 meters or 24 meters, and shallow seismic surveys were conducted to determine the attitude and continuity of near-surface materials. Lithologies, wave attenuation, P- and S-wave velocities, and other data were carefully logged. Ultimately, three of these boreholes will have accelerometer packages installed downhole.

Electric Power Research Institute Dense Strong-Motion Array

About eight kilometers east of the TFA is the Electric Power Research Institute (EPRI) Dense Strong-Motion Array. It has 13 surface and 8 subsurface accelerometers and, like the TFA, is three-dimensional. The pattern of surface accelerometers in the EPRI array is shaped like a "Y." CDMG will install three additional surface accelerometer stations at each limb of the array, extending the limb lengths from about 100 meters to 1 kilometer. Sensor separation in the dense array is a few tens of meters, compared to instrument separations of about 2 to 3 kilometers for the strong-motion array. The close spacing of instruments in the dense array will enable scientists to determine the approach direction of earthquake waves and the spatial variation of high-frequency strong ground motion. The inner instruments (4 surface, 12 subsurface) at the apex of the array, which comprise the area of a full-scale nuclear reactor containment structure, are designed to provide data for the siting of nuclear powerplants. At this same site, the USGS has installed 10 three-component geophones on each of the same pads as the centrally positioned surface accelerometers. These geophones are much more sensitive than the accelerometers and will record local microearthquakes that will not trigger the accelerometers. Consequently,

they may provide the only data from the array until the anticipated main shock occurs.

USGS Differential Strong-Motion Array

A dense seismograph array similar to EPRI's is being installed by the USGS 10 kilometers southwest of the San Andreas fault. This array consists of 14 surface accelerographs and 14 collocated geophones in a 5-square-kilometer area. This array will be able to record the entire range of seismic activity, from microearthquakes to the main shock. The data from this dense array will help scientists understand the effect of local geology on the ground motions because, whereas both this array and the EPRI/CDMG array will record the same earthquakes, the geologic conditions on either side of the fault are different.

Liquefaction Array

Liquefaction is a ground-failure process that occurs when a soil mass, subjected to vibrational stress (such as during an earthquake), experiences a significant shear-strength decrease that results from high pore pressure due to water saturation. For example, during the 1964 Alaskan earthquake, the spectacular Turnagain slide, which destroyed about 75 homes, was probably due in part to liquefaction of one or more saturated sand layers. Also in 1964, a magnitude 7.5 earthquake near Niigata, Japan, caused liquefaction that resulted in the dramatic tilting of several four-story apartment houses.

To further understand the physical process of liquefaction, the USGS and EPRI have selected a site near Parkfield to install instrumentation that includes accelerometers and piezometers. The accelerometers will measure strong ground motion, and the piezometer will measure changes in hydrostatic pressure. Also, eight bench marks are precisely located with calibrated elevation markers to measure the surface subsidence that may occur because of any liquefaction. The purpose of this project is to monitor pore pressures in a particular sand layer as it undergoes liquefaction and to simultaneously record the acceleration levels within the layer. These data will lead to a better understanding of ground failure due to liquefaction and will enable engineers and scientists to improve their capability to predict the magnitude and extent of failure due to liquefaction.

Pipeline Experiment

An important part of the Parkfield experiment relates to the response of lifeline facilities (pipelines,

canals, bridges, and so forth) to fault movement and ground vibration. Prompt restoration of these facilities in damaged areas is essential to recovery of normal activities.

One particular lifeline test is for pipelines and was designed by Weidlinger Associates of Palo Alto to investigate the response of continuously welded and jointed pipelines to ground vibration and relative ground displacement. A typical use of welded pipelines is to convey oil and gas; jointed pipelines may be used to transport water or sewage. The location of this test is purposely close to a creepmeter operated by the USGS that spans the San Andreas fault zone and produces a record of fault movement. The pipeline segments are placed at 30 degrees and 60 degrees to the strike of the San Andreas fault. Fault movement detected by sensors within the pipelines will be correlated with the creepmeter record of fault movement, and pipeline response will be separated into components of bending and extension.

The design of continuously welded buried pipelines assumes that the strain of the fault zone may be diffused along the pipeline by friction between the soil and pipe within the fault zone. Calculation of expected pipeline response to fault movement has been made using various methods, which result in significant difference in response to the anticipated fault displacements near Parkfield. Thus, actual field observations of pipeline response to an earthquake will be unique and will assist in identifying the proper mode of calculating pipeline response to fault movement.

Ductile iron pipe used in the construction of water lines has push-on joints that can accommodate 5 degrees of rotation and about 2 inches of extension without leaking. For the Parkfield test, extensional and rotational detectors will be used at push-on joints to determine how the fault movements are accommodated by the joints and along the pipe. This test is expected to provide valuable data for current design approaches and to provide insight into how fault movement is accommodated by jointed pipe.

Instrumented Structures

Although the Parkfield area is rural in character, it has manmade structures common to other areas of California. The schools in Parkfield and nearby Shandon are being instrumented for the purposes of determining the response of standard schoolhouse designs to strong ground shaking. Also in the Parkfield area, a California Department of Forestry facility (constructed in 1952 of unreinforced masonry) will be instrumented. Other structures, such as bridges, are being discussed as potential sites for instrumentation.

Scientific Goals of the Parkfield Earthquake Prediction Experiment

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Several unique circumstances of the Parkfield experiment provide unprecedented opportunities for significant advances in understanding the mechanics of earthquakes. To our knowledge, there is no other seismic zone anywhere where the time, place, and magnitude of an impending earthquake are specified as precisely. Moreover, the epicentral region is located on continental crust, is readily accessible, and can support a range of dense monitoring networks that are sited either on or very close to the expected rupture surface. As a result, the networks located at Parkfield are several orders of magnitude more sensitive than any previously deployed for monitoring earthquake precursors (a preearthquake change in strain, seismicity, and other geophysical parameters). In this respect the design of the Parkfield experiment resembles the rationale for constructing a new, more powerful nuclear particle accelerator: in both cases increased capabilities will test existing theories, reveal new phenomena, and suggest new research directions.

It is well known that previous observations in seismogenic regions, while showing occasional evidence of earthquake precursors (for example, foreshock seismicity), have disclosed no single, simple set of events preceding earthquakes. Certainly no claim can be made that diagnostic precursory signals will be recorded at Parkfield or that any signals that might be recorded would universally precede earthquakes. However, given the strongly focused nature and high sensitivity of the Parkfield monitoring networks, there can be little doubt that new and unexpected features of the earthquake mechanism will be uncovered and that significant constraints will be placed on the mechanics of precursory processes.

Seismological observations around the world have resulted in the concept of the "seismic cycle," which describes for a given section of a fault the seismicity before, during, and after large periodic earthquakes.

Each large shock is followed by an intense period of aftershock activity, then by a relatively long interseismic period of deformation and infrequent seismic activity, and finally perhaps by a period of smaller shocks culminating in the next large shock. The cycle—large shock, aftershocks, interseismic deformation, precursory activity—then repeats. The duration of the seismic cycle is hundreds of years for long sections of fault that rupture in great earthquakes. At Parkfield, the duration of the seismic cycle is 22 years, the length of the Parkfield fault section is 25-35 kilometers, and the “large” earthquake is a magnitude 6 shock.

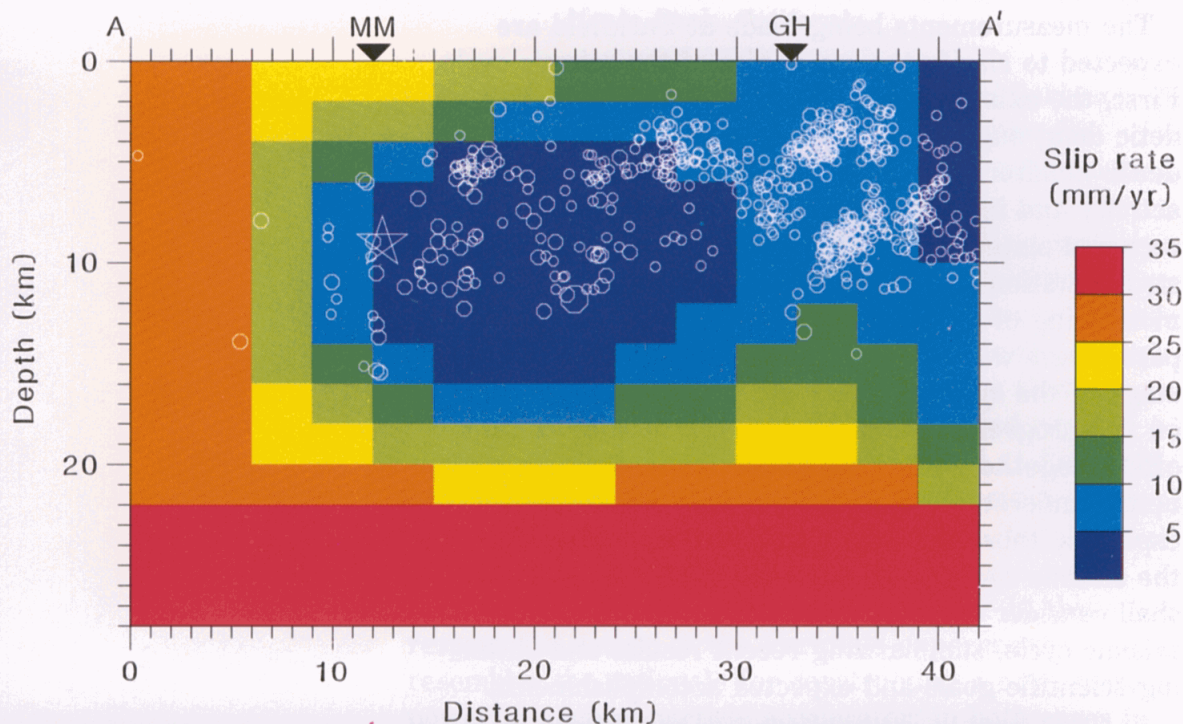
The measurements being made at Parkfield are expected to clarify the mechanics of the seismic cycle. First, the existing store of regional seismic and geodetic data, augmented since 1978 by increasingly dense monitoring, document the small earthquake activity and interseismic crustal straining that have occurred since the last shock in 1966. Further, instrumentation now in place for continuous or periodic monitoring of seismic and crustal strain-related parameters will supply unparalleled detail on the final stage of the cycle and also will provide valuable data on slip progression and the final distribution of fault offset; together, this information will contribute to a better understanding of interseismic deformation, especially those patterns that occur near the end of the seismic cycle. In the discussion that follows we shall consider the different phases within Parkfield’s seismic cycle, summarizing recent results and outlining scientific goals and expected accomplishments.

Interseismic Fault Slip and Seismicity

After the 1966 Parkfield earthquake, research increased significantly on crustal deformation and small earthquake activity for this segment of the San Andreas fault, and analysis of the resulting data has clarified the relation between fault slip and minor seismicity both at the time of the 1966 shock and subsequently. Using repeated observations from as many as 60 geodetic survey lines measured by precise laser ranging, USGS scientists have delineated the pattern of interseismic crustal deformation since 1966, a process which enabled them to map the aseismic slip distribution on the San Andreas fault at Parkfield. This analysis defines a region of little or no slip in the interseismic period that coincides approximately with the region of maximum slip in 1966, as defined by the distribution of aftershocks in 1966. That is, the region that slipped in 1966, causing the 1966 earthquake, has become increasingly slip deficient since 1966. In fact,

a comparison between the geodetically determined 1966 slip and the cumulative post-1966 slip indicates that nearly all of the strain released by slip in 1966 has reaccumulated, independently suggesting that the next magnitude 6 shock at Parkfield is imminent.

These data on interseismic slip distribution and seismicity supply a framework for interpreting the regional mechanics of the San Andreas fault at Parkfield. In terms of scientific goals of the prediction experiment, they provide an effective standard or baseline against which to compare any anomalous changes that present detailed monitoring may reveal.



Interseismic slip rate pattern (1966 to 1988) for Parkfield section of San Andreas fault inferred from geodetic measurements. MM and GH are locations of Middle Mountain and Gold Hill, respectively. Locations of 1966 aftershocks (circles) and main shock (star) concentrate in regions of relatively low interseismic slip, suggesting that slip on rupture zone of 1966 earthquake is lagging behind slip to the northwest of Middle Mountain.

Precursory Fault Failure

What little is known about the process of precursory fault failure is derived largely from fortuitous observations of arguably precursory activity or from fault failure models extrapolated from laboratory measurements on rock samples. Laboratory measurements of the frictional properties of rock surfaces do make explicit predictions about precursory behavior, suggesting that earthquakes should be preceded by measurable aseismic slip. However, neither the magnitude, duration, or spatial distribution of precursory aseismic slip are well constrained by existing field

observations. At one extreme, precursory slip might extend over all the eventual rupture area or beneath it, have significant amplitude, and begin weeks or months before the main shock. At the other extreme, precursory slip, if present at all, might be locally confined near the main shock hypocenter (point of rupture initiation) and begin only seconds before the main shock, resulting in catastrophic failure with no detectable precursors.

Which of these extreme scenarios is closer to the actual fault behavior at Parkfield—and elsewhere—may depend significantly on the degree of spatial heterogeneity in the frictional properties of the fault zone. It may also depend on the notable spatial fault-plane heterogeneity observed during an earthquake rupture period. It would be surprising if these heterogeneities apparent during earthquakes did not also influence fault zone behavior in the interseismic and preseismic phases of the seismic cycle.

The high-sensitivity strain and seismicity networks now in place monitoring the final stages of the earthquake cycle at Parkfield will help constrain the magnitude, duration, and spatial extent of precursory fault failure on this section of the San Andreas fault. The constraints provided are likely to be substantial. First, the emplacement of seismometers in 200- to 300-meter-deep boreholes results in greater detection sensitivity for small earthquakes and better fidelity in recording their source effects. Further, the carefully selected locations and low background noise of the borehole seismographs means that extremely small foreshocks, even those as small as magnitude -0.25 , can easily be detected. Subsurface emplacement ensures that seismograms will not be degraded by the complex wave propagation, scattering, and attenuation that occurs in near-surface rocks and unconsolidated sediments. At the same time, the borehole strainmeters and the borehole water level sensors will record very subtle strain changes; the concentration of this borehole instrumentation and its isolation from near-surface environmental strains will provide redundant recording of tectonic strain perturbations as small as 10^{-7} that occur over periods of weeks (over shorter time periods, the strain sensitivity is greater because noise levels are lower). These detectability thresholds translate into precursory slip sensitivity of as little as a few millimeters averaged over the 25-kilometer-long rupture plane or somewhat greater slip confined to smaller subregions of the fault.

Coseismic Strain Release

The more than 100 strong-motion accelerographs within about 30 kilometers of Parkfield will provide an unprecedented data set of coseismic strain release for reconstructing the detailed history of seismic slip from the instant of rupture initiation to the cessation of fault movement. In particular, the installation of a specially designed array of accelerometers will pinpoint the specific places on the rupture plane where the high-frequency strong shaking, which is particularly damaging to structures, originate. These strong-motion observations will also help define the mechanical heterogeneity on the Parkfield rupture zone, a property which may well influence the extent, magnitude, and timing of precursory faulting processes.

Postearthquake surveying along the approximately 60 lines of the local geodetic network will permit determination of the coseismic slip distribution on the fault. It will be important to compare this distribution both with that obtained for the 1966 earthquake and with the cumulative slip deficit since 1966. The first comparison will establish the degree of similarity between the two shocks. The second bears on the detailed recurrence feature's of Parkfield earthquakes: if it is the slip magnitude in the 1966 shock that determines the time to the next event, the behavior conforms to a "time predictable" model of earthquake recurrence; if the slip amplitude in the next event is determined by the interearthquake time interval, the behavior conforms to a "slip predictable" model of earthquake recurrence.

Aftershock Period

An additional, even more refined comparison between the next Parkfield main shock and the 1966 event will be that of the spatial and temporal distribution of the aftershocks. Seismologists generally expect that any dynamic differences between the two main shocks or their slip distributions will be reflected here; however, even if the two events are seismologically and geodetically indistinguishable, it will be of interest to determine the ways in which this sameness is reflected in the aftershock sequence.

The USGS Plan for Short-Term Prediction of the Anticipated Parkfield Earthquake

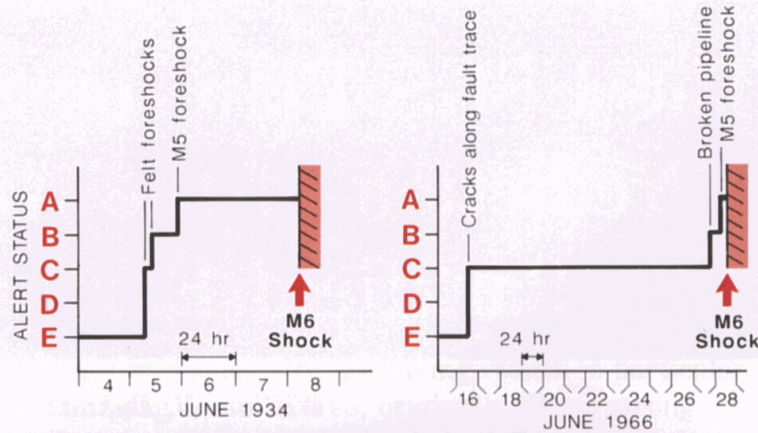
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Aside from the goal of better understanding the Parkfield earthquake cycle, it is the intention of the U.S. Geological Survey to attempt to issue a warning shortly before the anticipated earthquake. Although short-term earthquake warnings are not yet generally feasible, the wealth of information available for the previous significant Parkfield earthquakes suggests that if the next earthquake follows the pattern of "characteristic" Parkfield shocks, such a warning might be possible. Focusing on earthquake precursors reported for the previous "characteristic" shocks, particularly the 1934 and 1966 events, the USGS developed a plan* in late 1985 on which to base earthquake warnings for Parkfield and has assisted State, county, and local officials in the Parkfield area to prepare a coordinated, reasonable response to a warning, should one be issued.

Several types of observational networks operated near Parkfield are used in the USGS warning plan. The data from these network's are analyzed continually to monitor the earthquake potential status; if anomalous, an alert is indicated. Four alert levels (A, B, C, and D) have been defined. D-level alerts are defined as those alerts that occur frequently and represent a low level of concern; A-level alerts are defined to be infrequent and imply that the anticipated Parkfield shock is imminent.

<i>Alert level</i>	<i>Probability, in percent, of shock in next 72 hours</i>
E (normal conditions)	0.03 to 0.7
D	0.7 to 2.8
C	2.8 to 11
B	11 to 37
A	>37

*U.S. Geological Survey Open-File Report 87-192.



Plausible sequence of earthquake alert levels preceding the 1934 and 1966 Parkfield earthquakes. Alert level plan was devised by the USGS in 1985. These concocted "histories" are based on recorded foreshocks in 1934 and 1966 and anecdotes consistent with significant precursory fault creep in 1966. The 1934 and 1966 earthquakes would have been preceded by A-level alerts (by design of the alert level criteria); in contrast, there were no felt foreshocks or anecdotes of precursors before Parkfield earthquakes in 1881, 1901, or 1922.

The USGS warning will be directed to the California Office of Emergency Services (OES), which has the responsibility in California to disseminate hazard warnings to the public, to county and local officials, and to the press. A public warning will be issued by the OES whenever the USGS declares an A-level alert. Level A alerts not followed within 72 hours by the anticipated Parkfield earthquake are false alarms. Levels B, C, and D signify periods of increased earthquake likelihood but are not of sufficient concern to warrant public warnings. The following example of the June 1986 alerts illustrates how the USGS plan works.

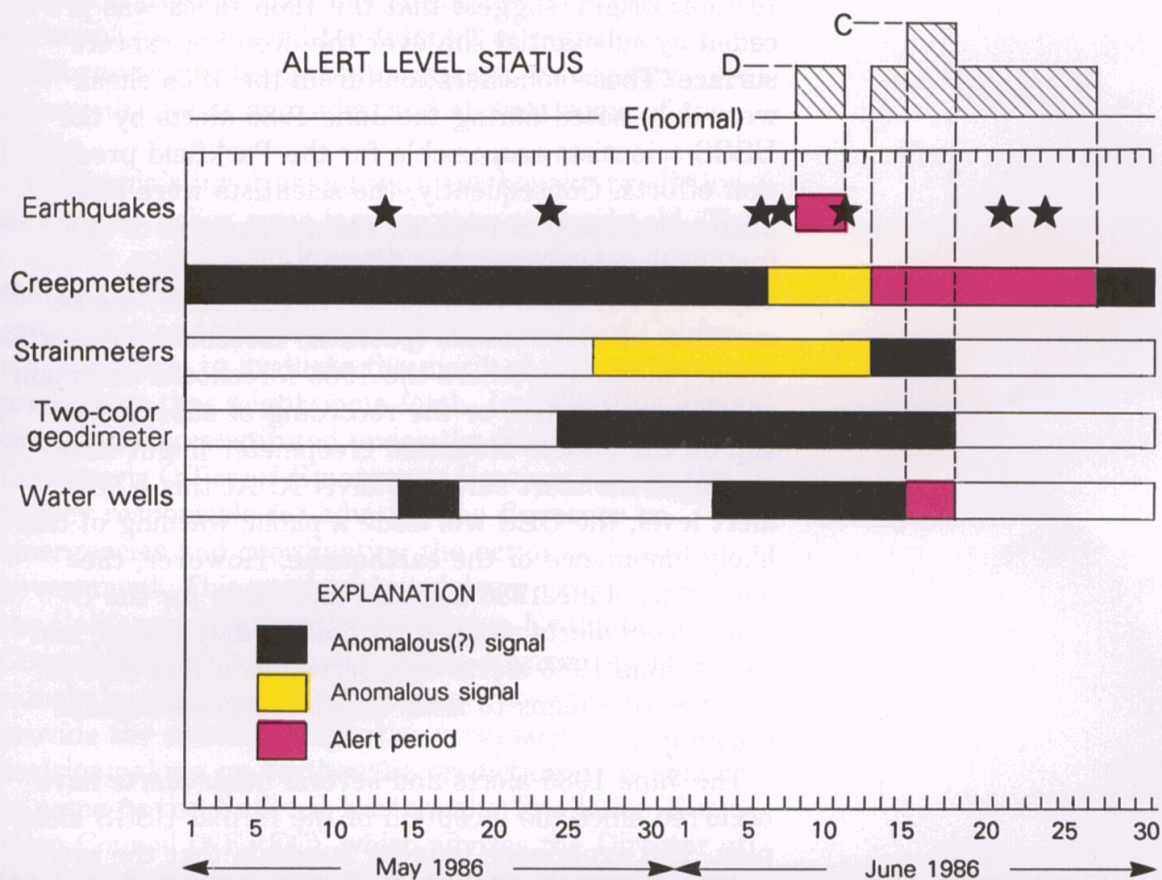
1. From June 6 to 8, a series of small (magnitude 1) shocks beneath Middle Mountain resulted in a D-level alert; however, this alert ended on June 11, 72 hours after the last shock in the series. The earthquake that occurred on June 11 was only coincidentally related to the end of the D-level alert and was not large enough to begin another alert.
2. From June 6 to 13, a surge in creep on the San Andreas fault recorded by the Taylor Ranch creep-meter was sufficient to warrant a D-level alert.
3. On June 15 water-level fluctuations in the Turkey Flat and Joaquin Canyon wells were sufficient to produce a D-level alert. Because of rules established for combining simultaneous D-level alerts, a C-level alert was declared on June 15. The water-level fluctuations ended shortly thereafter, and so the C-level alert ended on June 18, 72 hours after the last unusual

water-level change. The unusual surge in creep recorded by the Taylor Ranch instrument continued for several more days; the D-level alert for those data did not end until June 27.

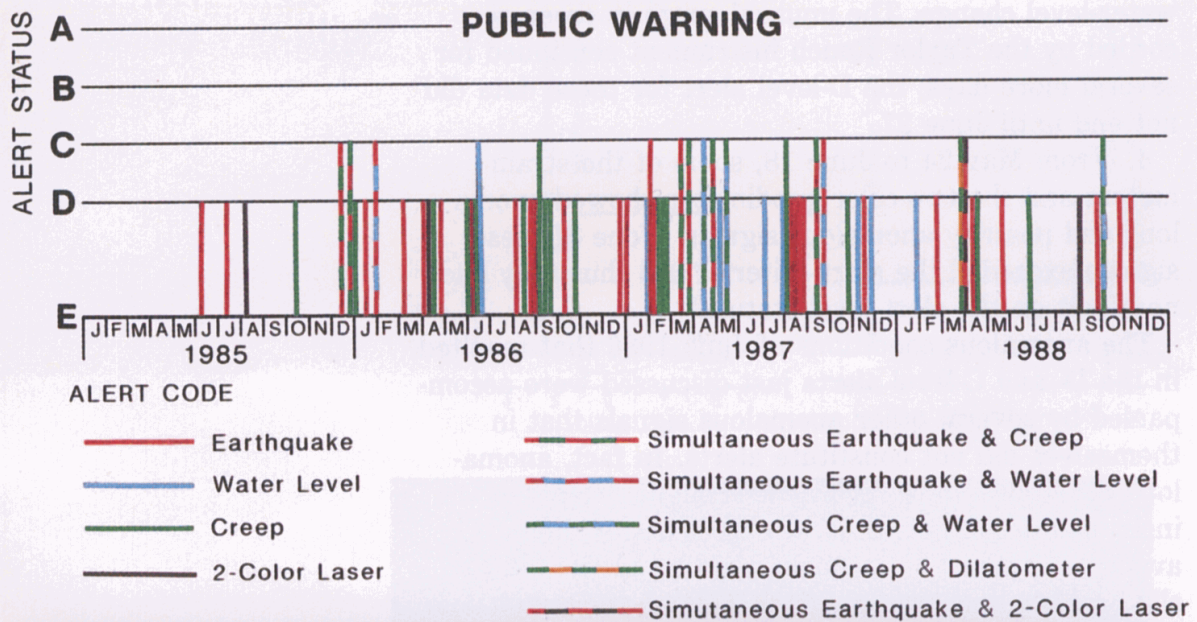
4. From May 24 to June 18, some of the strainmeters and the two-color geodimeter showed anomalous and possibly anomalous signals. None of these signals exceeded the alert criteria, and thus they had no affect on the alert level status.

The anomalous conditions of June 1986 that resulted in the D- and C-level alerts just discussed were accompanied by several other anomalous signals that in themselves did not constitute alerts. In fact, anomalous conditions were recorded throughout most of the instrumentation networks. On the basis of the data available, most of the signals could be attributed to slip on a shallow section of the San Andreas fault just south of Parkfield.

It was this same section of the San Andreas where, 12 days before the 1966 magnitude 6 earthquakes, Japanese seismologists visiting Parkfield found fresh-appearing cracks. These cracks, if they were of



Earthquakes recorded for and anomalous creepmeter, strainmeter, two-color geodimeter, and water well signals recorded for Parkfield in May and June 1986. These observations led to a sequence of D- and C-level alerts in mid-June (see text for details). Absence of color in bars indicates that no anomalous signals were recorded.



Earthquake prediction alerts from 1985 to December 1988 at Parkfield. D-level alerts have resulted from small earthquakes (potential foreshocks), fault creep, fluctuation of water levels in wells, and changes in length of observation lines in the two-color laser geodimeter network. C-level alerts have resulted from small earthquake, fault creep, fluctuation of water levels in wells, and simultaneous D-level alerts on independent networks.

tectonic origin, suggest that the 1966 shock was preceded by substantial slip over the eventual rupture surface. These considerations from the 1966 shock were duly noted during the June 1986 alerts by the USGS scientists responsible for the Parkfield prediction efforts. Consequently, the scientists were at a heightened state of readiness in anticipation of any further developments that might be precursors to the expected Parkfield earthquake. In particular, the occurrence of more shocks (potential foreshocks) beneath Middle Mountain, where the 1966 foreshocks and main shock were located, or the recording of substantial slip on the Middle Mountain creepmeter might have escalated the alert status to level A. At this USGS alert level, the OES will issue a public warning of the likely imminence of the earthquake. However, the anomalous June 1986 signals responsible for the D- and C-level alerts stopped soon after they began, and so the June 1986 alerts only served as a test case of the scientific plans to issue a short-term earthquake warning.

The June 1986 alerts and several other alerts have occurred since the inception of the formal USGS alert plan. The experience thus far suggests that the system is practicable. As more experience with the system is obtained, the USGS will refine the details of the alert criteria, with the goal of decreasing the frequency of alerts and increasing the degree of earthquake likelihood within the A alert level.

State Public Policy Issues Involved With the Parkfield Prediction Experiment

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The earthquake-prediction experiment at Parkfield may well be the most important such experiment currently underway worldwide. Its importance, however, extends beyond the scientific data that will be gathered and whether those data can provide reliable prediction methods. Important public policy lessons are being learned (and are yet to be learned), and these lessons may be transferable to other parts of California and the nation. Indeed, the Parkfield experiment has captured the interest of numerous Californians, including State officials, emergency managers, the news media, and at least some of the public.

California's involvement with earthquake prediction as a public policy issue is more than a decade old. The scientific enthusiasm in earthquake prediction during the mid-1970's led to the formation of an advisory group that met regularly at the University of California, Berkeley, to evaluate the merit of any earthquake predictions that might come forth. In 1976, this group was formally constituted under the Director of the Governor's Office of Emergency Services (OES), the agency responsible for advising the Governor on emergencies and coordinating the action of State government. This earthquake advisory group, called the California Earthquake Prediction Evaluation Council (CEPEC) was, and still is, a panel of professionals in seismology and geology whose purpose is to provide the scientific expertise necessary for public decisionmaking on earthquake prediction. It is similar in name to the National Earthquake Prediction Evaluation Council (NEPEC), which advises the Director of the U.S. Geological Survey in its task of carrying out the Federal research responsibilities for earthquake prediction and issuing hazard advisories to the States.

Under recently revised operating procedures, CEPEC continues to advise the Director of OES on seismic risk and earthquake forecasts, but its role has

evolved with the changing nature of earthquake research and the needs of OES. Initially, CEPEC defined its role largely as a peer review panel to be convened when a member of the scientific community voiced predictions that might have public safety implications. The panel was to evaluate the validity of these predictions; however, few materialized, and those that did were found to lack scientific credibility. With Parkfield, however, the prediction is not the product of insights or research of one individual, but the collective effort of a number of scientists. Moreover, the prediction comes from another government agency. While CEPEC is still prepared to review predictions that emerge suddenly from the work of a single investigator, its new procedures emphasize the assessment of long-term earthquake potential in California as well as possible short-leadtime indicators of significant earthquake activity.

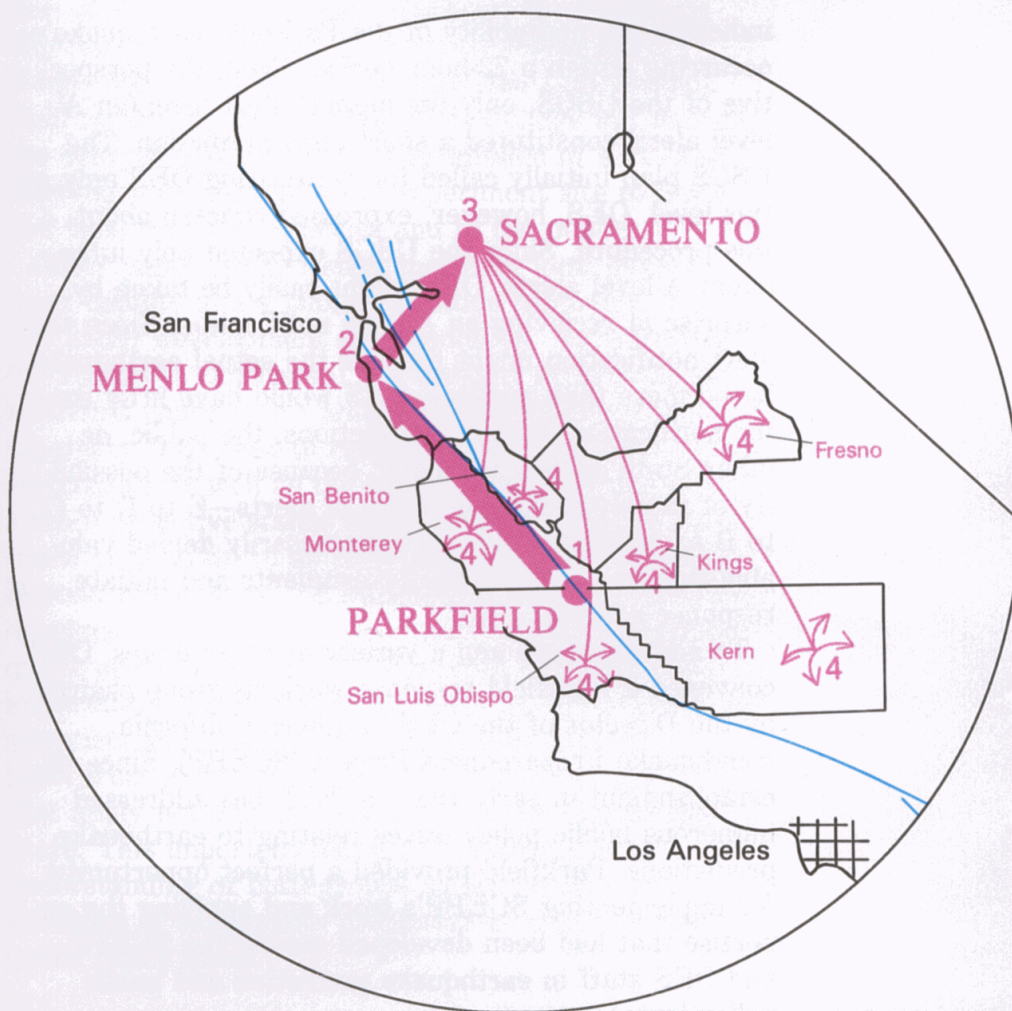
Prior to the public announcement by the USGS of the Parkfield prediction, CEPEC reviewed the prediction experiment and concluded that the scientific basis of the experiment was credible. CEPEC then advised the Director of OES that his agency should develop plans to respond to a possible short-term alert. In fact, CEPEC's advice to OES helped influence the very course of the Parkfield experiment, particularly in encouraging the USGS commitment toward issuing a short-term warning to the State of California. In fact, CEPEC had a key role in changing the USGS program at Parkfield from a scientific effort to one where operational earthquake prediction was an important component. This change represented a dramatic advance in public policy, transforming Parkfield from an interesting scientific project to one that included the major issue of public safety.

Nevertheless, the Parkfield experiment posed several dilemmas for OES. The first involved the size of the anticipated Parkfield earthquake. The USGS experiment centered on predicting the next "characteristic" Parkfield earthquake, an event of approximately magnitude 6. Such an event would not, if the damage pattern conformed to that of the 1966 earthquake, cause widespread damage. However, the April 1985 USGS public announcement of the Parkfield prediction contained a disturbing reference from OES's perspective to an unspecified probability of the Parkfield earthquake "growing into" a larger event, potentially a magnitude 7.0 earthquake.* Not only would this earthquake shake a larger area, the level of

*Editor's Note: The probability estimates are based on poorly constrained geologic relationships; current USGS estimates suggest a 1 to 10 percent chance of this larger shock.

ground motion could be severe enough to cause significant damage in at least three counties. Because of these public safety concerns, OES, CEPEC, NEPEC, and the USGS have worked together to refine estimates of the likelihood of this larger event and its potential impacts. Current policy of both OES and the USGS includes the provision that whenever the next Parkfield earthquake occurs, both agencies will remain on alert in an effort to cope with a potential larger shock.

A second dilemma was related to the prediction alert levels developed by the USGS. These levels are based on a USGS assessment of instrument data from various Parkfield monitoring sites that, collectively,



Flow of information resulting from an A-level alert at Parkfield. Signals from USGS instruments at Parkfield (1) are telemetered to the USGS Western Region Headquarters in Menlo Park (2) for analysis by USGS scientists. The California Office of Emergency Services (OES) in Sacramento (3) is notified by the USGS for all A-, B-, and C-level alerts. A-level alerts are immediately transmitted by OES to county governments (4) using established OES emergency communication channels. County officials also have established procedures to relay the warning to such groups as law enforcement agencies, fire departments, utility companies, and school districts.

"Tabletop exercise" held at West Hills College, Coalinga, in February 1987. The exercise simulated communication, warning, and response procedures for an A-level Parkfield alert.



indicates the probability of the Parkfield earthquake's occurring within a 72-hour period. From the perspective of the USGS, only the highest alert level (an A-level alert) constituted a short-term prediction. The USGS plan initially called for notifying OES only at this level. OES, however, expressed concern about this procedure. Since the USGS expected only infrequent A-level alerts, OES might easily be taken by surprise at receiving an A-level notification. Since the alert notification might precede the actual earthquake by no more than minutes, OES would have little time for notification of local jurisdictions, the public, or other State agencies. Finally, because of the possibility of rapidly escalating levels of alerts—E to D to C to B to A—OES would be unnecessarily denied valuable time to contact local governments and initiate response actions.

To address these and a variety of other issues, OES convened a Parkfield response working group chaired by the Director of the OES Southern California Earthquake Preparedness Project (SCEPP). Since its establishment in early 1981, SCEPP has addressed numerous public policy issues relating to earthquake predictions. Parkfield provided a perfect opportunity for implementing SCEPP's work and applying the expertise that had been developed among the SCEPP and OES staff in earthquake prediction and public policy issues.

In October 1986, the OES Parkfield response working group, which included representatives of the USGS, the California Division of Mines and Geology, and local governments in the area surrounding Parkfield, made its recommendations to the OES Director. The group's recommendations were adopted by OES. The OES Sacramento Warning Center set up procedures to receive a Geologic Hazards Warning for Parkfield from the USGS in Menlo Park and provide a warning to local jurisdictions. The content of mes-

sages originating with the USGS and those to be transmitted to local jurisdictions by OES was determined in advance. An agreement between OES and the USGS provided for notification to OES of B- and C-level alerts to assure familiarity with the procedures as well as time to mobilize personnel should the A-level alert be reached. Also initiated was a planning program consisting of prediction response checklists for local jurisdictions and State agencies.

In February 1987 the California Specialized Training Institute (CSTI), OES's training division, conducted a tabletop exercise to walk through the communication, warning, and response procedures. In attendance were all principal agencies with response roles in an actual prediction alert: the USGS, the California Division of Mines and Geology, Caltrans, the California Highway Patrol and six Counties (Fresno, Kern, Kings, Monterey, San Benito and San Luis Obispo). Held on the campus of West Hills College in Coalinga, the exercise simulated the transmission of a 72-hour warning from the Parkfield experiment site to State and local response agencies and to the public.

Other public policy issues, including local government liability and a public education campaign, are still under development and resolution. Nevertheless, the Parkfield experiment has brought significant and beneficial changes in California's emergency response capability. The need to respond to the prediction of an earthquake as well as the actual event has resulted in a more proactive stance among agencies whose traditional orientation to an emergency has been reactive. Beyond response to the Parkfield prediction, OES has developed a plan to respond to any short-term earthquake prediction issued in California. Perhaps most importantly, Parkfield has provided an opportunity for scientists and emergency-preparedness officials to learn from each other and address common problems that apply not only in Parkfield but throughout the State. This important dialogue has deepened the understanding of both groups to the promise and problems of earthquake prediction as a science and a public policy issue.



Suggested Reading

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By agreement between the U.S. Geological Survey and the California Division of Mines and Geology, a series of articles summarizing the Parkfield earthquake experiment is being jointly published in this issue of "Earthquakes and Volcanoes" and in various issues of "California Geology," the monthly publication of the California Division of Mines and Geology, edited by Mary C. Woods. We welcome this cooperation and hope that the two publications will provide helpful background for this unique seismological experiment.